FRIEND
and
HOLLISTER

Induction Motors in
Concatenation

Electrical Engineering
B. S.
1907

UNIVERSITY OF ILLINOIS

May 28, 1907

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ROBERT OWEN FRIEND and VERNON LEO HOLLISTER

ENTITLED INDUCTION MOTORS IN CONCATENATION

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

Morgan Brooks

HEAD OF DEPARTMENT OF ELECTRICAL ENGINEERING

T A B L E   O F   C O N T E N T S.

PREFACE

Since there is very little literature and data available on induction motors connected in cascade, we have endeavored to obtain data which may lead to its adoption commercially, or, at least, give a better understanding of its operation. Not assuming that the following is at all exhaustive, but, in the light of the results obtained, we claim, that the future for tandem control is brighter, not only because of the more knowledge on the subject, but because of the satisfactory results that may be obtained as pointed out herein.

European engineers have recognized the benefits to be derived, by using this system; they have utilized the method; and found it satisfactory as is shown by its continued use. It remains for the American genius, we believe, to adopt and perfect its operation.

The laboratory work made necessary by the tests performed, required the services of at least three men. For services and kindly help rendered, we wish to thank Mr. Louis P. Cook, senior in electrical engineering, class of 1907.

(1) V. L. Hollister

(2) Robert O. Friend

1907.

INDUCTION MOTORS IN CONCATENATION.

Discussion of Tandem Operation.

Of the methods put forth for the variation of the speed of induction motors no method promises better returns than that of tandem control. By using this method the motors will start up with a large torque and attains a speed equal to one half the speed of a single induction motor connected to the line. Lower speeds however, may be obtained by inserting resistance in the secondary of motor number two, while higher speeds may be obtained by throwing the motors directly on the line. This gives a very wide variation of speed and at the same time an efficiency very nearly equal to the efficiency at full speed and greater than the efficiency of a system which is dependant upon resistance for the variation of speed. In addition to the above this method possesses the very desirable feature of small starting current.

Among some of the important disadvantages of this method is, the requirement of a very complicated controller to facilitate the operation of the motors in concatenation. Also the extra inductance provided by the primary of motor number two for the secondary of motor number one, reduces the torque of the latter and the power factor of the secondary circuit.

This method of speed control has been found to be successful in many European countries and is used principally in street car systems. For some reason, which can not be determined by the writers, this method has not been received very favorably by engineers in this country. Mr. S. P. Thompson, an English scientist,

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

speaks very highly of this method and in substance says, "There can be no doubt that for large powers such a method of speed control as the one in question is the only one likely to be adopted in the future."

THEORY OF INDUCTION MOTORS AND METHOD OF OPERATION.

It was observed in studying the phenomena of the direct current dynamo that when the armature conductors are cutting the magnetic field, the machine being on open circuit, that there is little or no reaction between the conductors and the field. When these conductors are carrying a current, however, a reaction occurs, and the greater that current the more turning effort is it necessary to supply to compel the armature coils to cut the field of flux. A short circuited armature tends to assume no motion relative to the magnetic field. Thus a Direct Current generator with its commutator short circuited by a band of copper, and with its fields suspended so as to be capable of rotation about the armature shaft; and, when its fields are rotated, tends to drag its armature at the same speed as is given to the field. By suitably winding the field and supplying and alternating (n+1) phase current to that winding a rotating magnetic field may be produced with a stationary field frame. Any short circuited armature winding placed in the above field tends to rotate at synchronous speed with the revolving magnetic field.

A machine built upon this principle is called an induction motor. This type of motor is in its present form, not a variable speed machine. To obtain a wide range of speed, at least, a very desirable feature, a great many devices have been proposed, and some of these are in practical use today. The usual method for starting as well as for reducing the speed is the introduction of

resistance into the secondary circuit. By this means the heavy currents usual at starting are avoided and the speed for any given output is reduced. A peculiarity of this method being that the torque remains the same, i. e., the output varies directly with the speed.

It may have been from endeavors to obtain variable speeds that the connection of two motors in concatenation was evolved.

The connection (known by this name) consists of leading the wires from the secondary of machine number one to the primary of motor number two. Figure number one shows diagrammatically the connections described above.

Assuming that the first machine is at standstill and an alternating current is applied to the primary windings, from a knowledge of transformer action it is easily seen that an alternating current is induced in the secondary winding equal to the primary current

$$Y \frac{\text{Primary turns}}{\text{Secondary turns}}$$

and it can also be seen that this secondary current has the same frequency as the primary current.

Consider the effect produced in the second machine, where the voltage impressed is equal to the original

$$\text{E. M. F. } X \frac{\text{Secondary turns}}{\text{Primary turns}}$$

of the first machine.

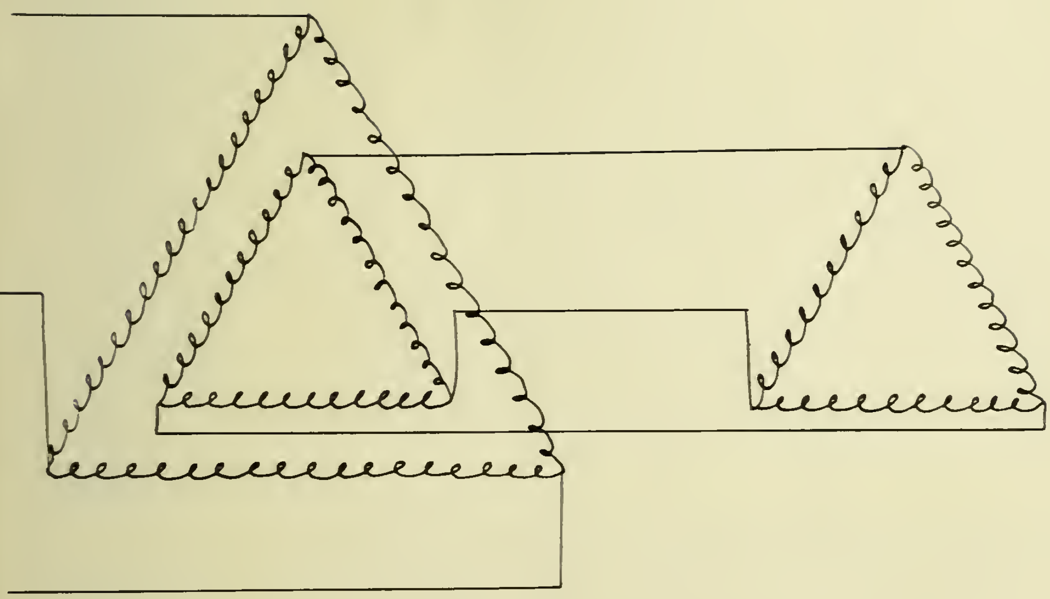


DIAGRAM I

The current is equal to that flowing in the secondary of the first machine, and at the same frequency as the primary current. Then the first machine is acting only as a transformer, and if the secondary of motor number two is short circuited we shall expect it to assume full speed.

Now, turning to the theory of the rotating field of an induction motor, with the secondary of the first machine clamped stationary, its conductors are cut by the alternate lines of force eminating from north and south poles. These poles follow each other, and any one of them makes a complete revolution in $\frac{P}{f \times 60}$ th part of a minute. Where P is the number of pairs of poles and f is the frequency of the impressed voltage: Thus, with a six pole machine and a frequency of 60, the time of one revolution, is $\frac{3}{60 \times 60} = \frac{1}{1200}$ th part of a minute, or R. the speed is equal to 1200 R. P. M., this being the speed of the rotating magnetic field.

Let it be assumed that the secondary of machine one is now released and is allowed to assume a speed of 300 R. P. M. It now has a speed of 1200-300 = 900 R. P. M. relative to the rotating flux. Due to this new condition, the frequency impressed on the second motor has changed, and is now

$$\frac{900}{1200} = 75\%$$

of its former value or 45 periods per second. The speed of the second machine, dependent upon the impressed frequency, has changed, and is now

$$N^1 = \frac{f \times 60}{p} = \frac{45 \times 60}{3} = 900.$$

Thus, we see that the speeds of the two motors are inversely proportional, and that the sum of the two speeds is equal to a constant, in this case

$$300 + 900 = 1200,$$

neglecting slip.

It may be readily seen that by controlling the speed of the first machine by a brake, or otherwise, the speed of second machine may be controlled through a wide range.

The most apparent drawback to this method of speed control is the large amount of turning effort exerted by the secondary of the first machine which must be overcome by a brake or other contrivance. A natural means of applying a brake to the secondary of the first motor in order to vary its speed is at once suggested viz., by placing a belt load on its pulley, driving a generator or other load. Then, by varying the load so applied, the speed of the first motor may be varied, and inversely to such variation will the speed of number two machine be changed.

The factor entering into this operation which prohibits the low speeds of the motor number two as well as the high speeds of motor number one is the voltage. From the equation of E. M. F. for a group of n conductors cutting a magnetic field $E = \frac{\phi n N}{10^8}$ it is seen that the induced pressure is proportional to the speed n, or to the rate and number of times the conductors cut such field. With a revolving magnetic field the conductors cutting the flux will have the greater E. M. F. induced in them when moving at the

greatest relative speed to the field, or when they have an absolute speed of zero. Thus, with the first secondary at standstill we have a maximum voltage impressed on the second primary, and with the first machine at, or near, synchronism, the voltage impressed on the second will be very small.

From the foregoing it is seen that, if the rotating conductors have no speed relative to the revolving magnetic field, there is no E. M. F. generated in the secondary since there is no cutting of the lines of force. Therefore, under these conditions there is no current flowing in the secondary, there is no appreciable reaction between the secondary and the magnetic field and the former immediately tends to slow down. The condition of smaller secondary speed thus produced gives a relative speed between the magnetic field and the secondary, causing, thereby, a cutting of the flux, an E. M. F., and a current in the secondary circuit. The resulting magnetic reaction between the rotating magnetic field and the secondary compels the latter to follow the former more closely. Following out these operations it is seen that a load on the secondary compels it to slow down, therefore, a greater current is necessary to produce the required magnetic reaction between the secondary and revolving field, and, therefore greater cutting of lines by the secondary conductors is necessary to produce the larger E. M. F. and current in the secondary, therefore, greater relative speeds between the field and secondary are found. This relative speed is called slip.

This thesis has for its object the investigation of the performance of induction motors when connected in concatenation. In the past it has been customary to not only connect the machines electrically, but, also, mechanically to the same shaft, thus compelling them to assume a speed equal to, or slightly less than, one-half synchronous speed.

It was conceived, however, that many of the difficulties met with in the above method might be eliminated by using the electrical connections alone. By this method the speeds of the two motors depend entirely upon the loads applied. By adjusting the loads applied the ratio of the speeds could be adjusted as desired. If motor number one was loaded so as to take a speed of 400 R. P. M. with a synchronism at 1200 R. P. M., then the speed of the second motor would be 800 R. P. M., but under any load its secondary slips behind and probably assumes a speed slightly less, say 775 R. P. M. With the above conditions fulfilled the ratio of speeds is

$$\frac{400 -}{800 -} = 1 / 2$$

To investigate the efficiencies, powerfactor, and general performance for different ratios of speeds is the scope of this work.

MATHEMATICAL THEORY.

Leaving out the quantitative expression for the performance of induction motors, the following equations will give the qualitative behavior satisfactorily.

Let E_2 = secondary E.M.F. at standstill

S = slip = 0 at synchronism and 1 at stand still

$S E_2$ = secondary E.M.F. at slip S.

It may be assumed for the simplification of the expression that the ratio of coils and turns per coil in primary and secondary is unity, hence

X_2 = rotor reactance at standstill in ohms

$S X_2$ = Reactance of rotor circuit of motor at slip S

R_2 = resistance of rotor coils of first machine.

Then

$$\sqrt{R_2^2+(S X_2)^2} = \text{impedance of secondary}$$

$$\frac{S E_2}{\sqrt{R_2^2+(S X_2)^2}} = I_2 = \text{secondary current}$$

$$\frac{R_2}{\sqrt{R_2^2+(S X_2)^2}} = \text{power factor of secondary}$$

The Torque

$$T = \frac{(S E_2) R_2 K}{\sqrt{R_2^2 + (S X_2)^2}}$$

Where K is a constant and if T is expressed in dyne centimeters

$$K = \frac{P n'}{4 \pi f}$$

Where p = number of poles

n = armature circuits

f = frequency

If the magnetic field be assumed to have a constant maximum value, T may be written

$$T = \frac{R_2 (S E_2) K}{R_2 + (S X_2)^2}$$

From this expression the following may be derived:

(1) The torque, but not necessarily the power, is a maximum when $R_2 = S X_2$ for maximum power slip and resistance are low as possible.

(2) When $R_2 = X_2$ the maximum torque occurs at standstill, determining R for this condition.

(3) The maximum torque = $\dfrac{E_2 K S.}{2 X_2}$

(4) Further at standstil the torque = $\dfrac{K E_2 R_2}{R_2 + X_2}$

(5) Maximum torque is inversely proportional to X, reactance, and may be increased by designing motor for low X.

(6) The output is proportional to the product of torque and speed. Therefore

$$\text{power } (P) = A\,(1 - S)\,\frac{R_2 (S E_2) K_2}{R_2^2 + (S X_2)^2}$$

A = Synchronous speed.

Analytical Theory for Induction Motors in Cascade

When two motors are connected in cascade, the reactance of the primary of the second machine is added to that of the rotor of the first machine, and conditions are changed thereby.

For the second machine let--,

m = slip

X_3 = reactance of the primary

X_4 = reactance of the secondary

R_4 = resistance of the secondary

R_3 = resistance of the primary

Z_3 = impedance of primary.

We will assume a ratio of primary turns to secondary equal to unity in both machines.

If X_3 equals the reactance of the primary of the second machine at a frequency of 60 and with its rotor at synchronism, then, if m is the slip, we can readily see that if m increases a larger current will flow, or that $X_3\ (1 - m)$ is the expression for the reactance at that slip.

The slip of the first motor decreases the frequency of the impressed voltage on the second motor and thus we may write, using S for slip of motor number one.

$$X_3\ (1 - m)S = \text{The reactance of the primary}$$

of the second motor.

For the smaller values of $\underline{s}$ this is not strictly true since we know that the reactance of the primary of an induction motor re-

duces to nearly a fixed quantity.

It probably may be more proper to assume that for the extreme condition of stand still when m has very large values,

that

S X_3 (1 - m + n) = the reactance at slips S and m where n is a constant.

Dropping n as of little consequence at small slips, we may write as the impedance of the primary circuit of the second motor

$$Z_3 = \sqrt{R_3^2 + [S(1-m)X_3]^2}$$

And we may also express the impedance of the secondary circuit

$$Z_2 = \sqrt{(R_3 + R_2)^2 + [S(1-m)X_3 + SX_2]^2}$$

Assuming, for simplicity that the machines have a ratio of primary turns to secondary turns equal to unity, then we may treat the above as the impedance of the primary circuit of the first machine.

The current in the secondary is

$$I_2 = \frac{SE_2}{\sqrt{(R_2 + R_3)^2 + [S(1-m)X_3 + SX_2]^2}}$$

The power factor is

$$\cos\phi = \frac{R_2 + R_3}{\sqrt{(R_2 + R_3)^2 + [S(1-m)X_3 + SX_2]^2}}$$

The torque T of the first motor is

$$T = s\,E_2\,I_2 \cos\phi\,K$$

Where s E_2 is the secondary E. M. F. at slip S, and K is some constant,

$$T = \frac{(S E_2)^2 (R_3 + R_2) K}{(R_2 + R_3)^2 + [S(1-m)X_3 + S X_2]^2}$$

This expression is a maximum when $(R_3 + R_2) = S(1 - m)X_3 + S X_2$ (For proof see note below) which occurs at standstill assuming S and K to remain constant.

This maximum torque is equal to

$$\frac{(S E_2) K}{2[S(1-m)X_3 + S X_2]}$$

Which we can see varies directly as the slip in both machines.

When the reactance of the two machines is negligible, an impossible condition,

$$T = \frac{(S E_2) K}{(R_3 + R_2)}$$

The output of the first machine is

$$P = A(1 - S) \frac{(S E_2)(R_3 + R_2) K}{[(R_2 + R_3)]^2 + [S(1-m)X_3 + S X_2]^2}$$

Where A is the synchronous speed.

We may draw the following conclusions for the first machine in the concatenated couple. Its power factor, its torque and its output increase for decreasing values of impedance of the second machine. Therefore, the greater slips for motor number two, the greater output for motor number one.

The latter statement must be modified, however, when we remember the expression for the impedance of a single induction motor

$$Z = \sqrt{R^2 + (SX)^2}$$

From this it may be seen that as the slip S increases the inductance of the rotor circuit increases and thus diminishes the decrease of the inductance in the primary if not actually raising the value of that inductance for large slips and low frequencies as are used in concatenation.

For the Second Machine

Assuming a small I Z drop in the secondary of the first motor, the voltage impressed on the second machine is $S E_2$, the current flowing in its primary is

$$I_2 = \frac{S E_2}{\sqrt{(R_2+R_3)^2 + [S(1-m)X_3 + S X_2]^2}}$$

The impedance of the secondary circuit of the motor number two is

$$Z = \sqrt{R_4^2 + (m X_4)^2}$$

The power factor is

$$\cos\phi = \frac{R_4}{\sqrt{R_4^2 + (m X_4)^2}}$$

The current flowing in this circuit is

$$I = \frac{m S E_2}{\sqrt{R_4^2 + (m X_4)^2}}$$

The torque exerted by the motor number two is

$$T_1 = \frac{(M S E)\ (R_4 K_3)}{(R_4^2 \quad (M X_2)^2}$$

Where K_3 is a constant. We may infer from the above that the torque second machine depends far more upon the slip of the first motor than upon its own slip.

Note:-- To prove the assertion that the torque as expressed by the equation

$$T = \frac{(R_2 + R_3)(S E_2)^2}{(R_2 + R_3)^2 + [S(1-m)X_3 + S X_2]^2}$$

becomes a maximum when

$$R_3 + R_2 = S(1 - M) X_3 + S X_2$$

we have but to take the first differential of the quantity with respect to R the total resistance and equate to zero and note whether its second differential is positive or negative.

Substituting

$$R_3 + R_2 = R \qquad\qquad (S E_2)^2 K = B$$

$$S(1 - M) X_3 + S X_2 = X$$

we have

#1 $$T = \frac{R B}{R^2 + X^2}$$

Let $T = \frac{1}{F}$

Then

#2 $$F = \frac{1}{B} \; \frac{R^2 + X^2}{R}$$

$$\therefore \quad F = \frac{1}{B}\left(R + \frac{X^2}{R}\right)$$

$$\frac{dF}{dR} = \frac{1}{B}\left(1 - \frac{X^2}{R^2}\right) = 0$$

$$X = R$$

Substituting this value of R in number two makes I a minimum which proves, obviously, that it is the value of R which makes number one a maximum.

Throughout this mathematical discussion X, reactance, has been regarded as an ohmic impedance, C. P. Steinmetz in his analytical equation for the induction motor considers the reactance from the stand point of counter E. M. F. s We believe the expressions as derived herein are more simple and serviciable than those derived from the counter E. M. F. theory.

DESCRIPTION OF MACHINES ON WHICH TESTS WERE MADE.

The machines upon which the following tests were made were two General Electric Induction Motors. The first was a 3 phase, 220 volt, 7 1/2 H. P., 60 cycle motor, at a speed of 1200 R. P. M. #94227 and is called Motor number one.

The other a 3 phase, 110 volt, 5 H. P., 60 cycle motor at 1200 R. P. M. #90034 and called motor number two.

The primary of motor #94227 is so wound that it can be used on single two, three, six or twelve phase circuits and has 72 slots and six poles or 4 slots per pole per phase. Each slot containing 18 #13 B. & S. copper wires. There are 72 coils, each coil composed of 9 turns of wire in series. These are so connected and ends brought out to a terminal block on the machine that the motor can be used on the different circuits mentioned above. Each phase has a resistance of .473 ohms and an inductance of .0137 henries.

The secondary of this motor has 54 slots and wound three phase and connected in (Y.) Each phase has two circuits and each circuit has 18 conductors in series. These conductors are made up of 2 copper bars .1"x.3" in parallel, there being 2 conductors per slot.

The primary of motor #90034 has 72 slots and six poles or 4 slots per pole per phase. There are 72 coils each coil made up of 10 turns of number thirteen B. & S. copper wires in series making 20 conductors per slot, 240 conductors are connected in

series per phase. Each phase has two circuits having a resistance of .[illegible] ohms and inductance of .01[illegible]5[illegible]

The secondary of this motor is wound three phase Y. and has 54 slots. Each phase has one circuit, consisting of 72 conductors in series. These conductors are made up of copper bars .1"x.3".

Plate number two shows the various connections necessary in order to run the motor *1 on single, two, three, six or twelve phase circuits.

In order to obtain a means of measuring the output of the motors and keeping the ratio of speeds of the two motors constant for a given test two rated dynamos were used. These dynamos were Edison bipolar machines of 7 H. P. capacity, 110 volts, 60 amperes when running at a speed of 1700 R. P. M. Each of these rated machines were belt connected to the motors.

The necessary power to drive the motors was taken from a 440 volt, two phase generator in the power plant to the University. By means of transformers and field rheostat this voltage was transformed down to about 190 volts.

The primary of motor number one was connected to receive two phase current and thrown directly on the 190 volt mains without using a compensator. By means of slip rings on the shaft of this motor three phase current was taken from the secondary of motor number one and led into the primary of motor number two.

TEST ONE

Ratio 1 - 1

Test number one has as its object the determination of the operating characteristics of the motors heretofore described connected in cascade, and having a ratio of speeds one to one.

The connections for this test are shown on diagram herewith. A quarter phase current is fed into the windings on the primary of the first machine. Its value is measured by a wattmeter and ammeter in each phase. A voltmeter is connected across one pair of leads, thus assuming that the voltage across each phase is the same.

The three phase Y connected secondary of machine one is connected to the three phase △ delta connected primary winding of the second machine.

The current in this three phase circuit is measured by the two wattmeters and ammeters as shown in the diagram. A voltmeter across one phase reads the pressure impressed on the second machine. The three phase Y connected secondary of machine number two is connected so that resistance may be inserted to start with and may be short circuited when up to speed, or nearly so.

A belt from motor number one drives a rated, direct current generator, the output of which is controlled by lamp banks, and measured by an ammeter and voltmeter.

Motor number two is similarly connected to a direct current generator for a load. To insure as nearly uniform conditions as

possible, the two Direct Current generators used were similar machines. Specifically, they were Edison Bipolar 7 H. P. 110 volt 50 A M P. 1700 R P M generators.

To obtain the speeds of the machines as well as to adjust them to a constant ratio of speeds, magnetic generators were belted to the shafts of the Direct Current generators. Voltmeters across the terminals of these magnetos read the pressure generated, which is proportional to the speeds.

To calibrate the magneto voltmeters to read speed, readings of speed and volts were taken through a wide range, and curves were plotted as in curve K, L, M.

The curve of M is determined from K and L for required ratio of speeds.

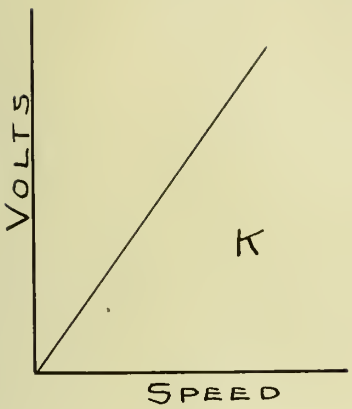
To obtain a reading the loads on the Direct Current generator were adjusted until the magneto voltmeters read corresponding voltages as obtained from curve M such as T and T^1, showing the ratio of speeds to be as desired.

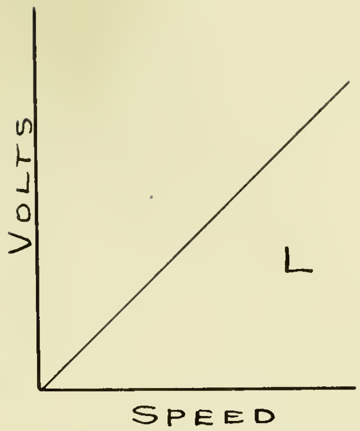
The efficiency for the first machine was calculated as follows:

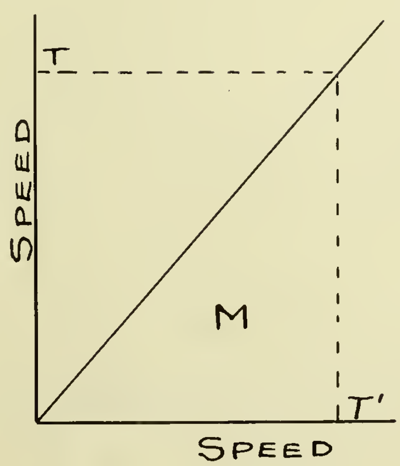
$$\text{Eff} = \frac{\text{Input in machine \#2} + \text{input into D.C.G. \#1}}{\text{Input machine \#1}}$$

The efficiency of the second machine =

$$\frac{\text{Input into D.C.Generator \#2}}{\text{Input into Motor \#2}}$$


VOLTS
K
SPEED


VOLTS
L
SPEED


T
SPEED
M
T'
SPEED

The power factor of three phase circuit is obtained by the formula

$$\operatorname{Tan} \theta = \frac{W_1 - W_2}{W_1 + W_2} \sqrt{3}$$

Where W_1 = larger reading of wattmeter

W_2 = smaller reading of wattmeter

The results of this test are shown graphically on plates 1_a and 1_b. The observed and calculated data following the curves.

Plate 1_a shows the power factor in phases A and B and the efficiency for varying input expressed in watts per phase.

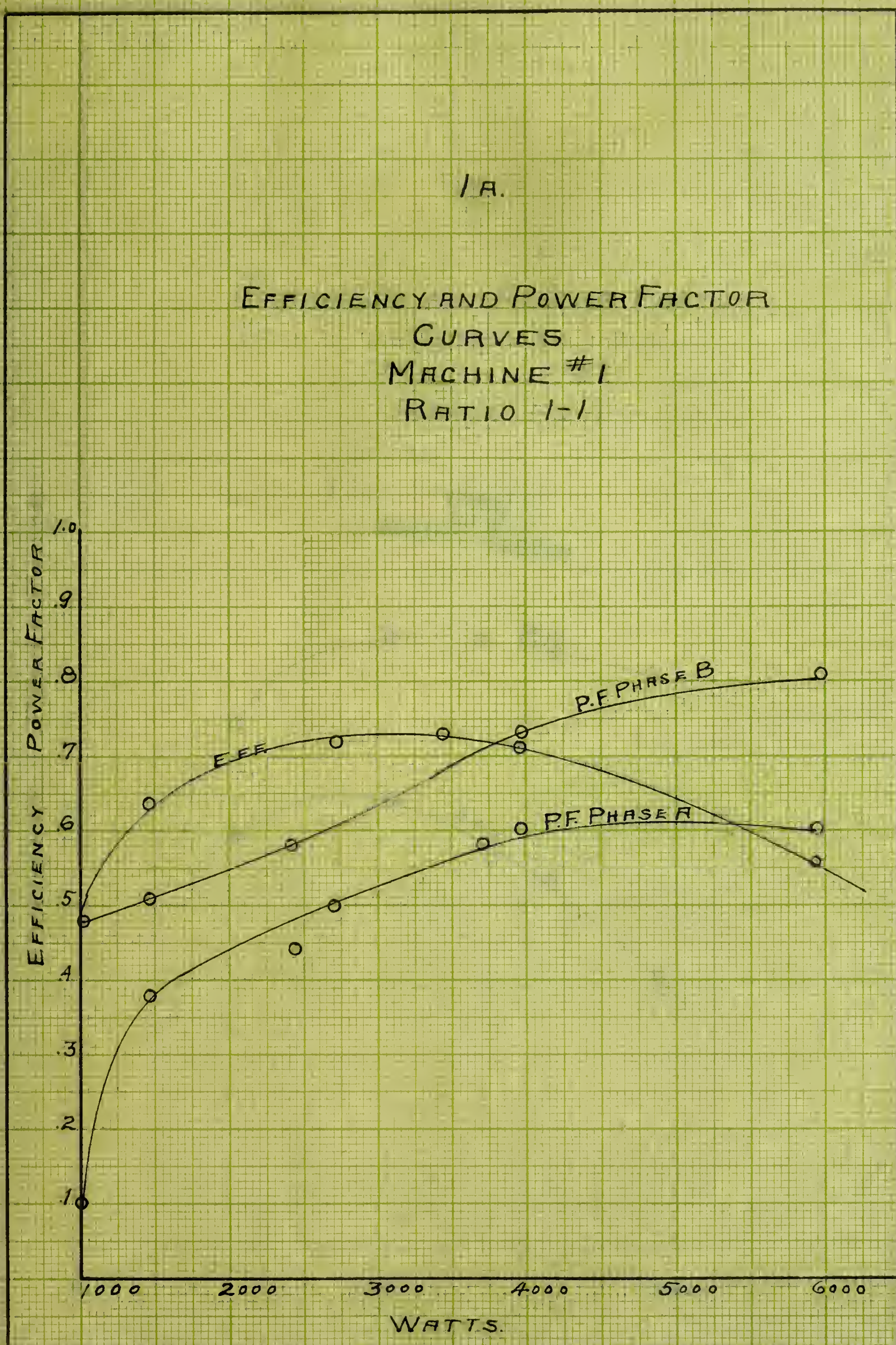
Plate 1_b shows the power factor and efficiency of machine number two.

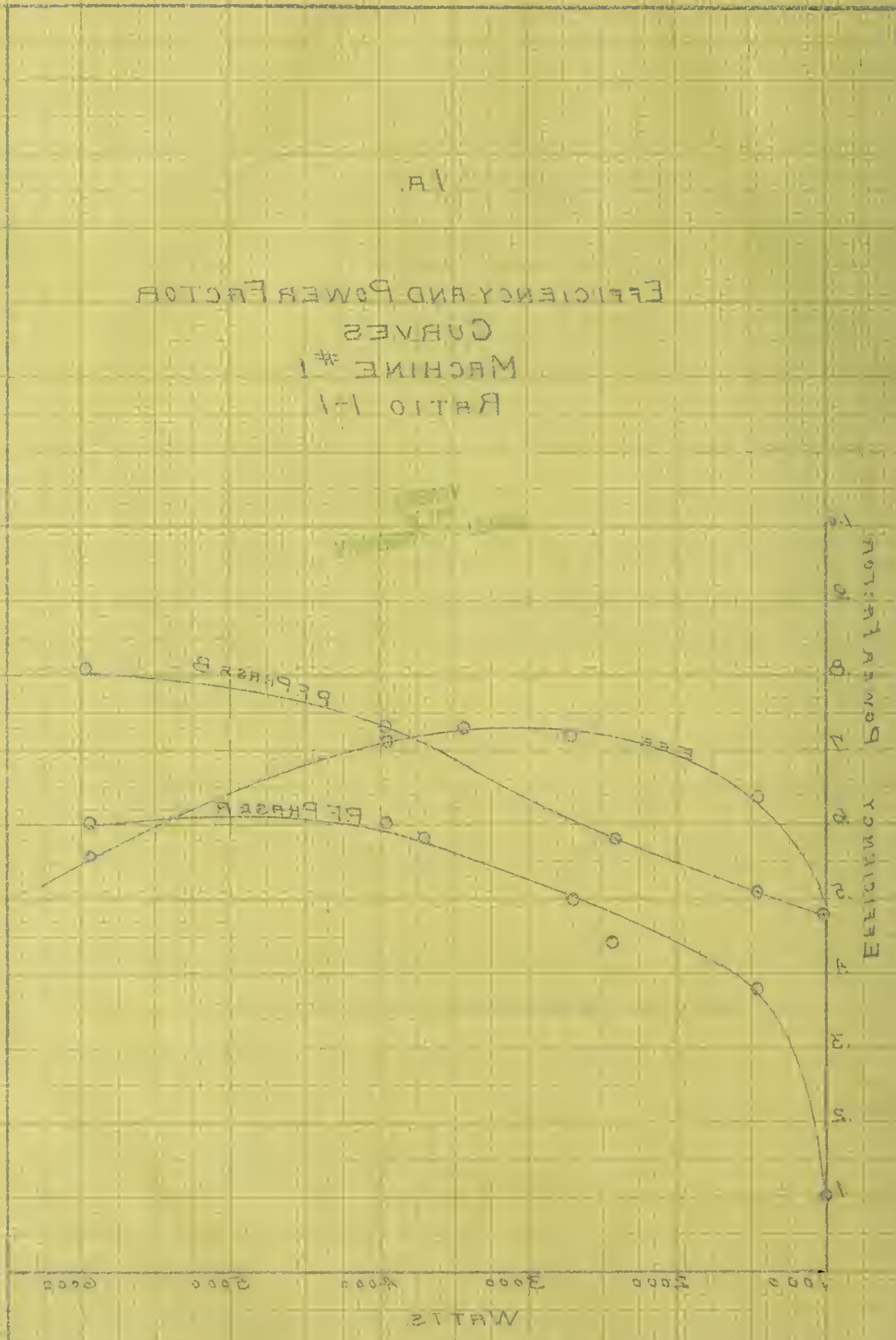
Both of these curves are self-explanatory.

If we were to compare the results of this test with that of a load test on machine one, the result would be far from favorable.

The performance of motor number one when used as a single induction motor is shown graphically on plate C.D. 1.

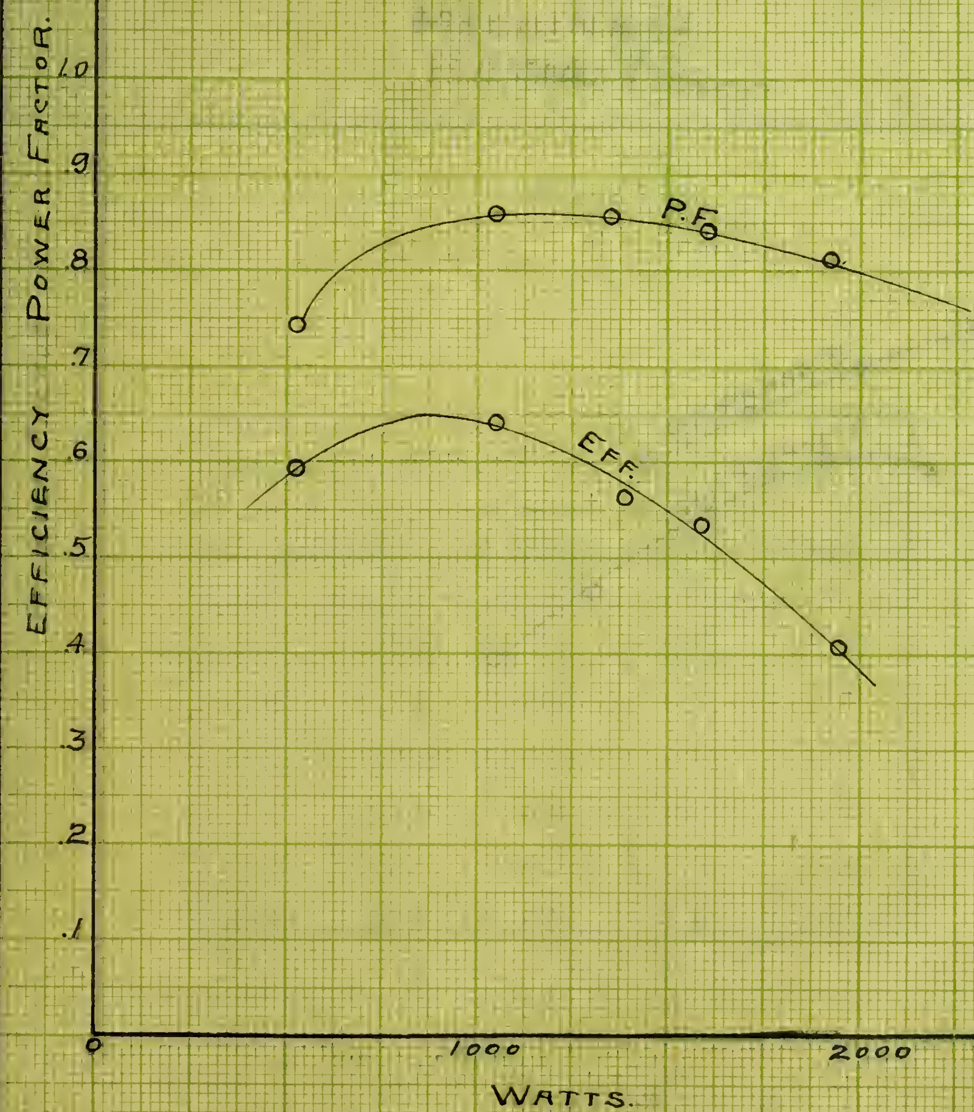
The larger power factor, the greater efficiency and larger output shown on that curve proclaim at once the superiority of the single induction motor over the concatenated couple.

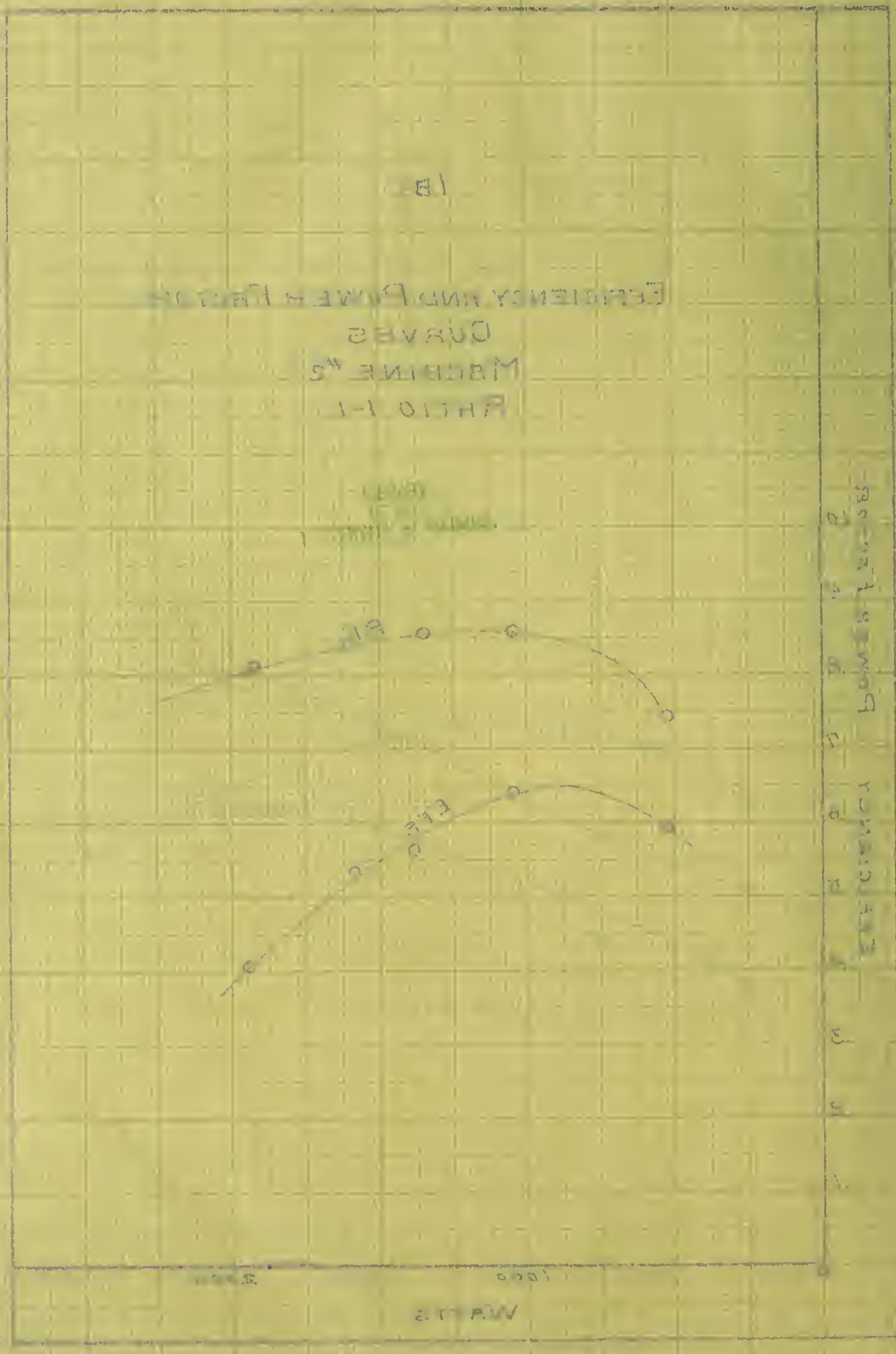

1A.
EFFICIENCY AND POWER FACTOR
CURVES
MACHINE #1
RATIO 1-1
EFFICIENCY POWER FACTOR
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
EFF.
P.F. PHASE B
P.F. PHASE A
1000
2000
3000
4000
5000
6000
WATTS.

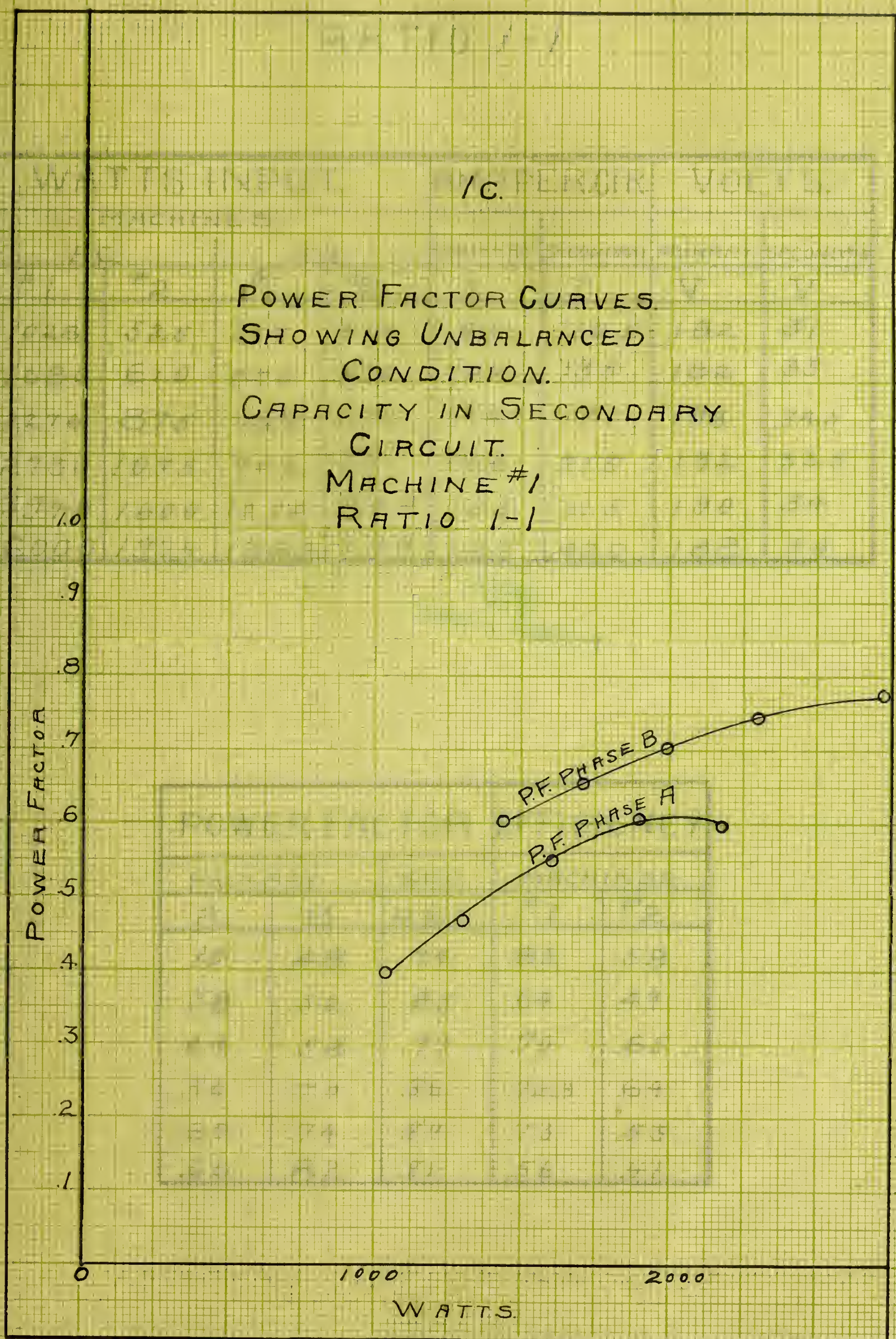

1A.
Efficiency and Power Factor
Curves
Machine #1
Ratio 1-1
PF Phase B
PF Phase A
Eff
Efficiency Power Factor
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1000
2000
3000
4000
5000
6000
Watts

1B.

EFFICIENCY AND POWER FACTOR
CURVES
MACHINE #2.
RATIO 1-1




18
Efficiency and Power Factor
Curves
Machine #2
Ratio 1-1
PF
EFF
2000
1000
Watts
Efficiency Power Factor


1c.
Power Factor Curves
Showing Unbalanced
Condition.
Capacity in Secondary
Circuit.
Machine #1
Ratio 1-1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
Power Factor
P.F. Phase B
P.F. Phase A
1000
2000
Watts.

RATIO 1-1

WATTS INPUT.				AMP. PER. CIR.		VOLTS.	
MACHINES				PRIMARY	SECONDARY	PRIMARY	SECONDARY
A.C.		D.C.					
#1	#2	#1	#2	I	I	V	V
1028	525	317	304	9.5	12.0	182	31
1680	610	470	396	10.2	13.5	182	33
2276	875	720	570	11.4	17.0	193	34.5
2730	1075	902	691	12.6	21.5	192	33.5
3940	1600	1258	849	15.5	31.5	190	34
6000	1975	1382	799	19.5	42.0	188	34

POWER FACTOR			EFFICIENCY	
PRIMARY		SEC.	MACHINES	
A	B	A.B.C.	#1	#2
.10	.48	.74	.82	.58
.38	.52	.85	.64	.49
.44	.58	.77	.70	.65
.50	.70	.86	.723	.64
.60	.74	.84	.73	.53
.60	.82	.81	.56	.41

TESTS 2, 3, & 4.

Ratios 1 - 2, 1 - 3, 1 - 5.

The results of the test with ratio of speeds 1 - 1 showed very plainly that the voltage impressed (approximately 60 volts) was too small for the particular machine. A ratio of 2 - 1 or a larger speed of this first motor would, therefore, be undesirable. The ratio of speeds determined upon were 1 - 2, 1 - 3, and 1 - 5. The pressure and frequency impressed on the second machine were thus increased.

The method of procedure was the same as in test number one.

The results obtained are plotted graphically on plates 2_a and 2_b for the ratio of 1 - 2, plates 3_a and 3_b show the results for test number three, and pltes 4_a and 4_b show the results of test number four.

A comparative study of the results obtained shows an increase in the efficiency of the first motor with a decrease of power factor for the higher ratios.

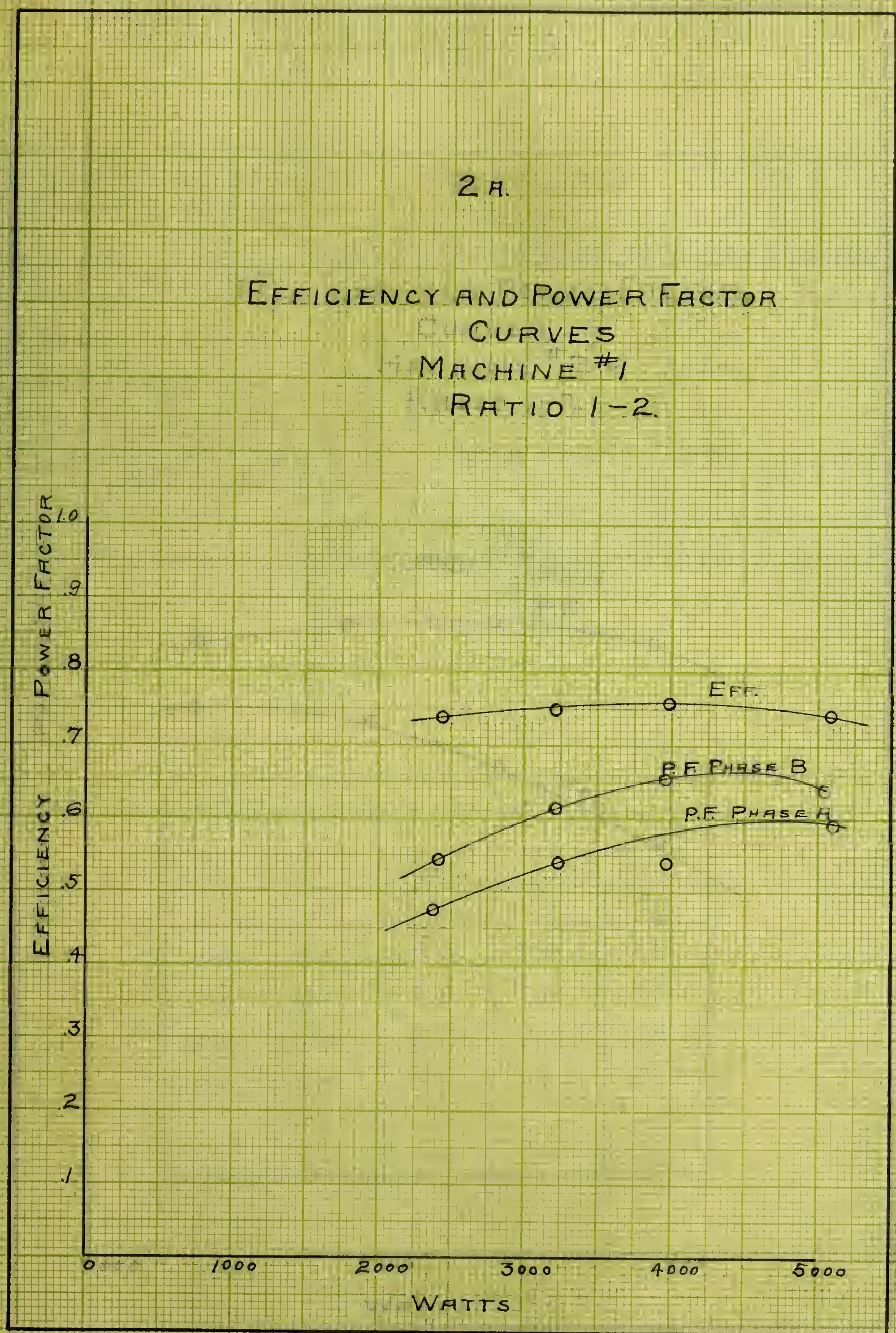
The efficiency and power factor for the second machine undergo less change than do those for the first motor, but the efficiency shows a marked increase between the test number one and test number two. Beyond the ratio 1 - 3 there is little change in these factors.

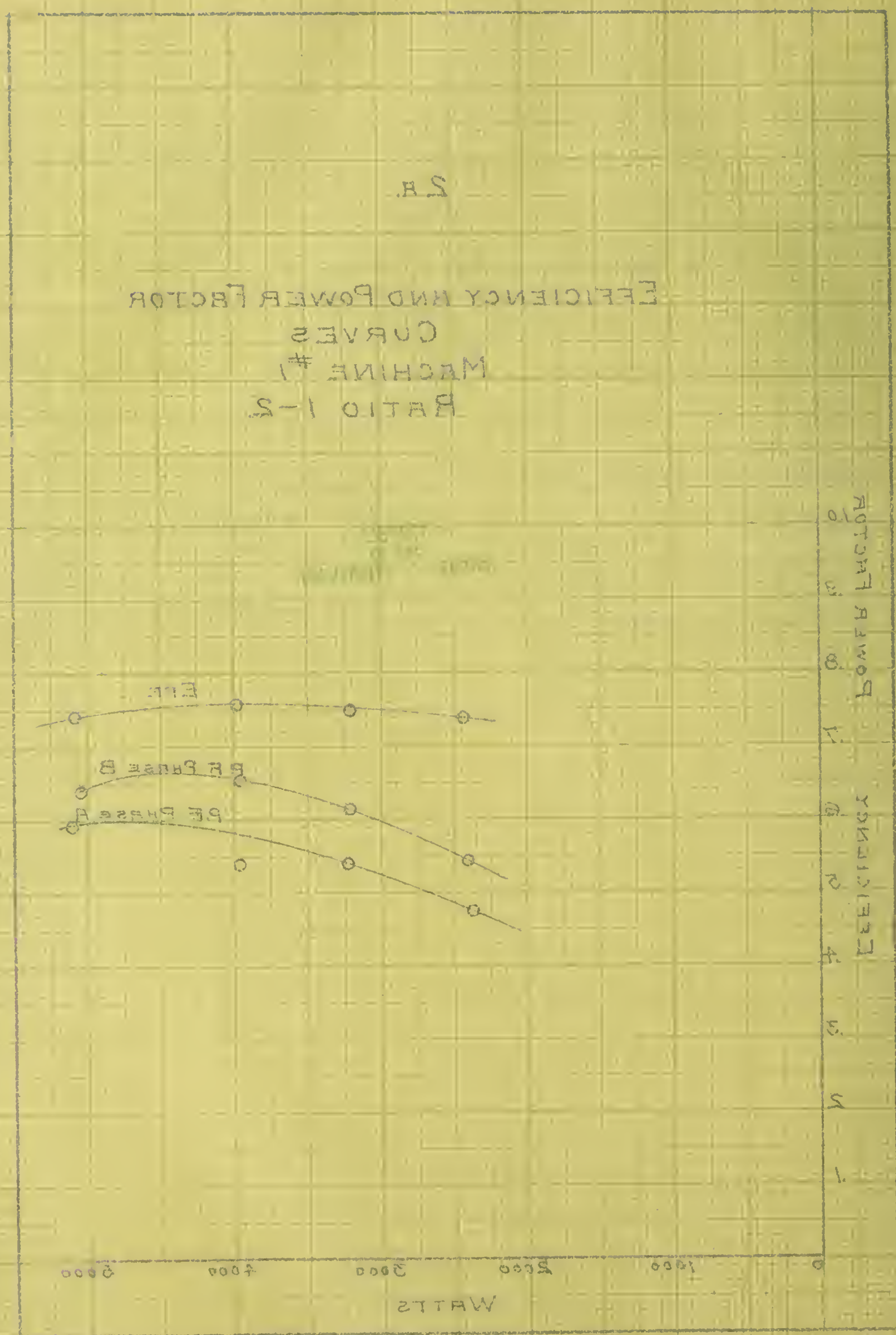
Plate number 4_c shows the increase of efficiency as the ratio is increased. On the curve ratio 1 - 5 is shown as 1/5 = .2, while ratio 2 - 1 is shown as 2. From this latter curve it is seen that

the greater ratio voltage and frequency, [illegible] on the second machine produce greater efficiencies.

It might be stated that the [illegible] the rule, the more efficient transformer it becomes.

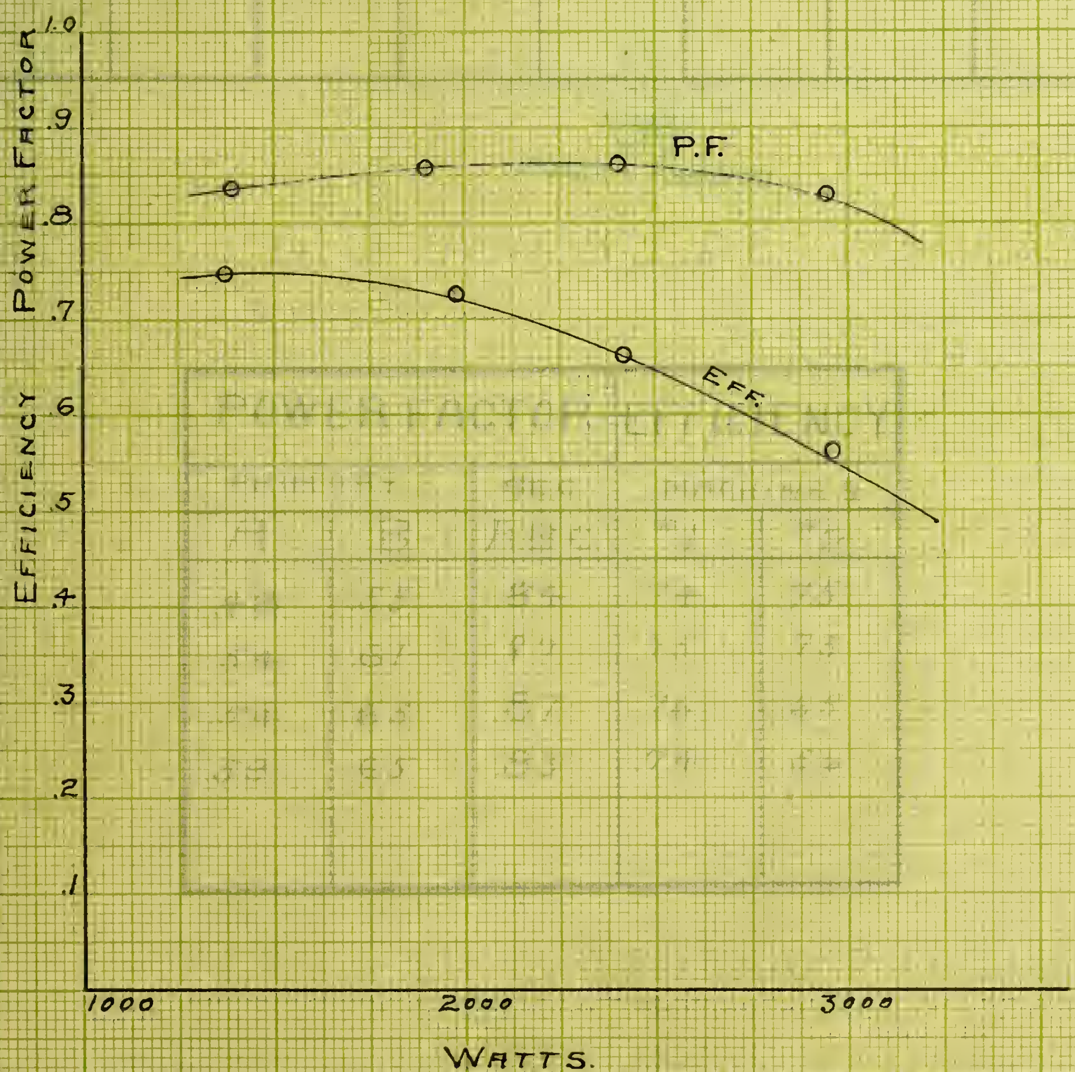
In determining the efficiencies no account has been taken of one factor, which, if not vitally effecting the results, would raise the figures here given. The belt losses between the Alternating Current motors and their Direct Current generators have been neglected throughout these tests, due to our inability to obtain accurate figures as to their value. Assuming, as is often done, that these belt losses amount to 2% of the input, the efficiencies would be raised by approximately that same percentage.


2 A.
EFFICIENCY AND POWER FACTOR
CURVES
MACHINE #1
RATIO 1-2.
POWER FACTOR
EFFICIENCY
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
1000
2000
3000
4000
5000
WATTS
EFF.
P.F. PHASE B
P.F. PHASE A


2 A.
EFFICIENCY AND POWER FACTOR
CURVES
MACHINE #1
RATIO 1-2
EFF.
PF Phase B
PF Phase A
POWER FACTOR %
EFFICIENCY
WATTS
1000
2000
3000
4000
5000

2 B.

EFFICIENCY AND POWER FACTOR CURVES.
MACHINE #2
RATIO 1-2.



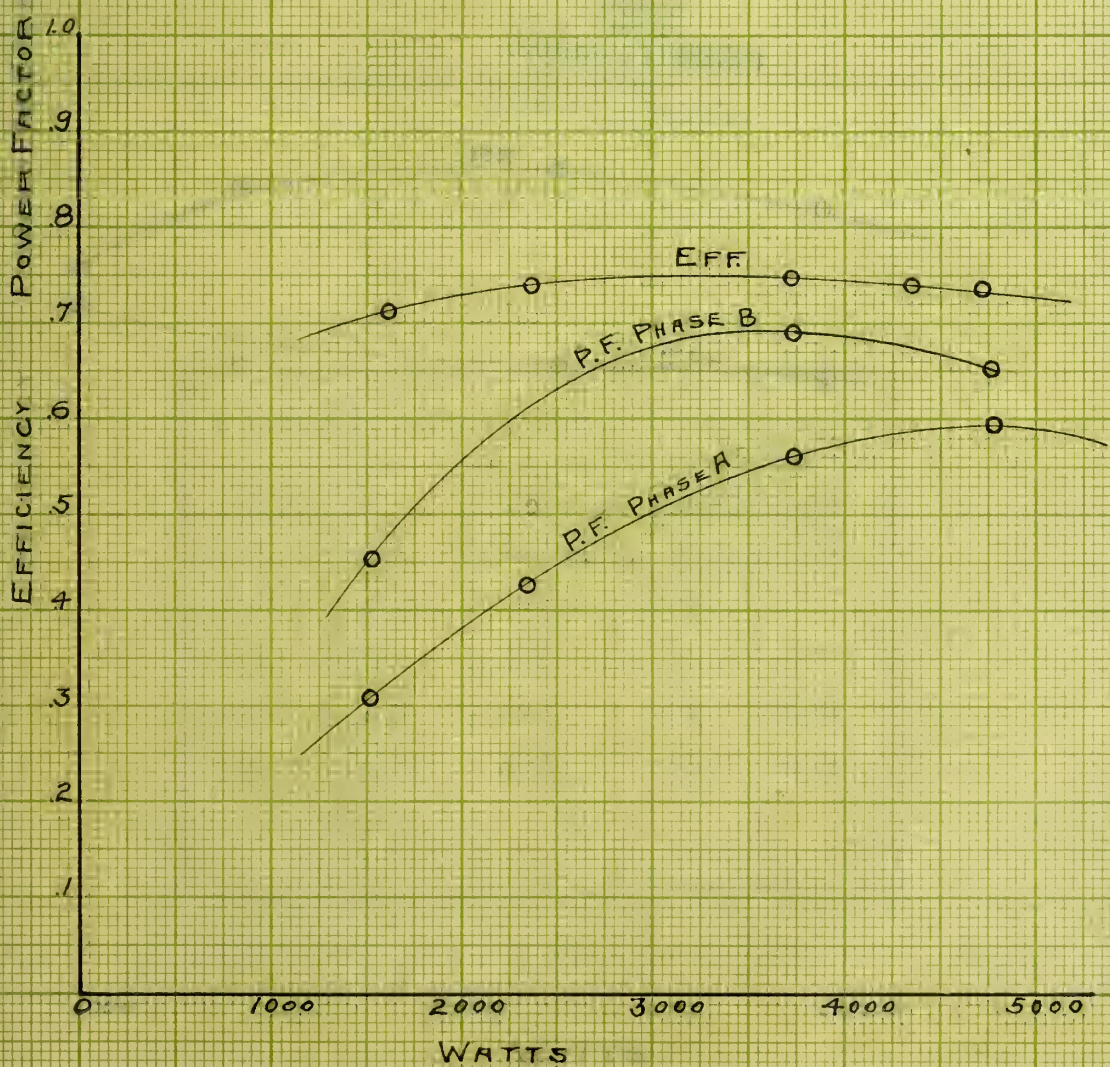
RATIO-1-2.

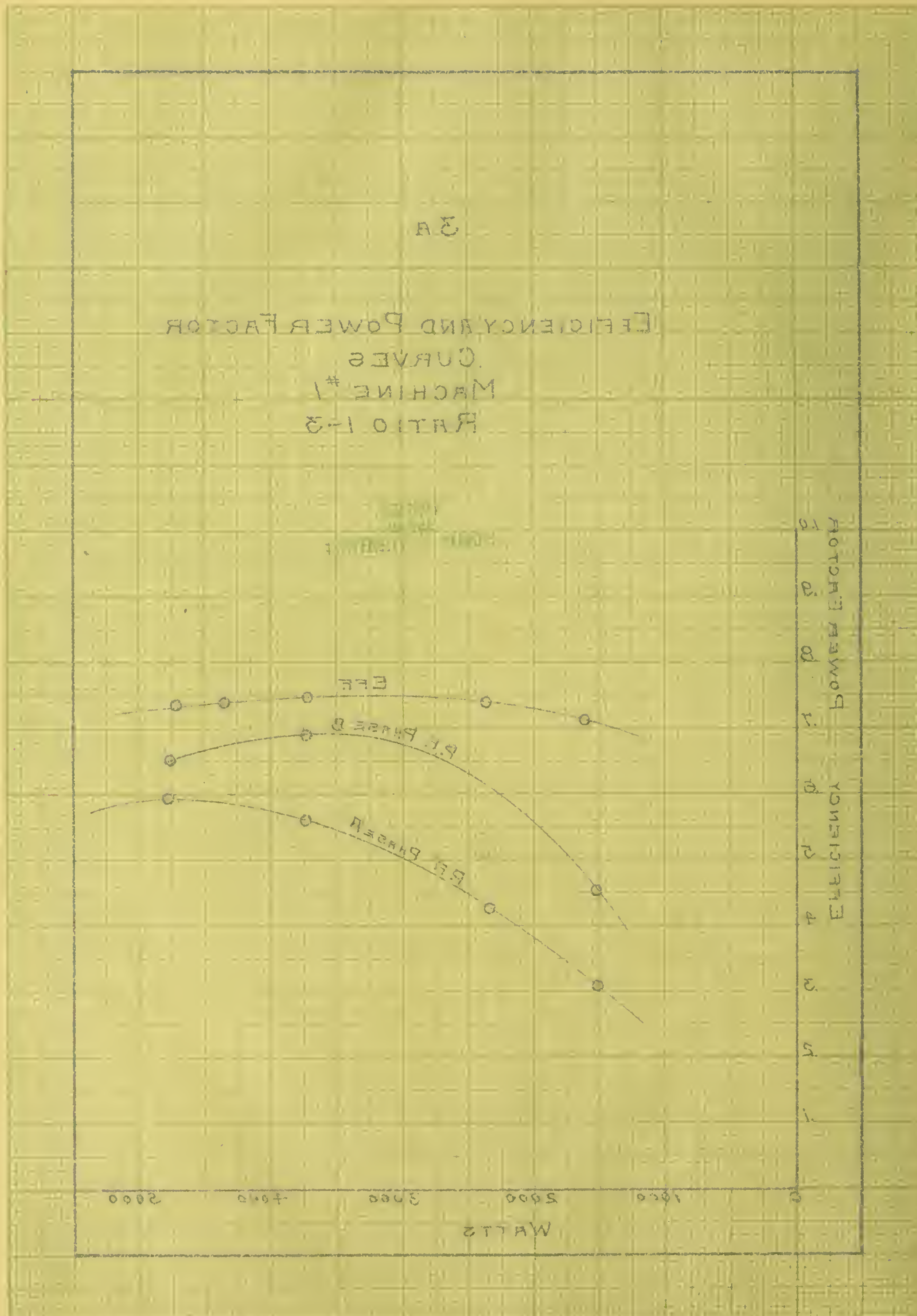
WATTS INPUT.				AMP.PER.CIR.		VOLTS.	
MACHINES							
A.C.		D.C.		PRIMARY	SECONDARY	PRIMARY	SECONDARY
#1	#2	#1	#2	I	I	V	V
2540	1400	475	1047	13.8	18.7	191	50
3220	1890	531	1376	15.3	25.2	194	52
3960	2370	646	1546	17.3	32.0	197	51
4880	2950	638	1676	20.8	40.0	198	51

POWER FACTOR			EFFICIENCY	
PRIMARY		SEC.	MACHINES	
A	B	A.B.C.	#1	#2
.48	.55	.84	.74	.75
.54	.61	.87	.75	.73
.54	.65	.87	.76	.65
.59	.65	.83	.74	.56

3A

Efficiency and Power Factor Curves
Machine #1
Ratio 1-3

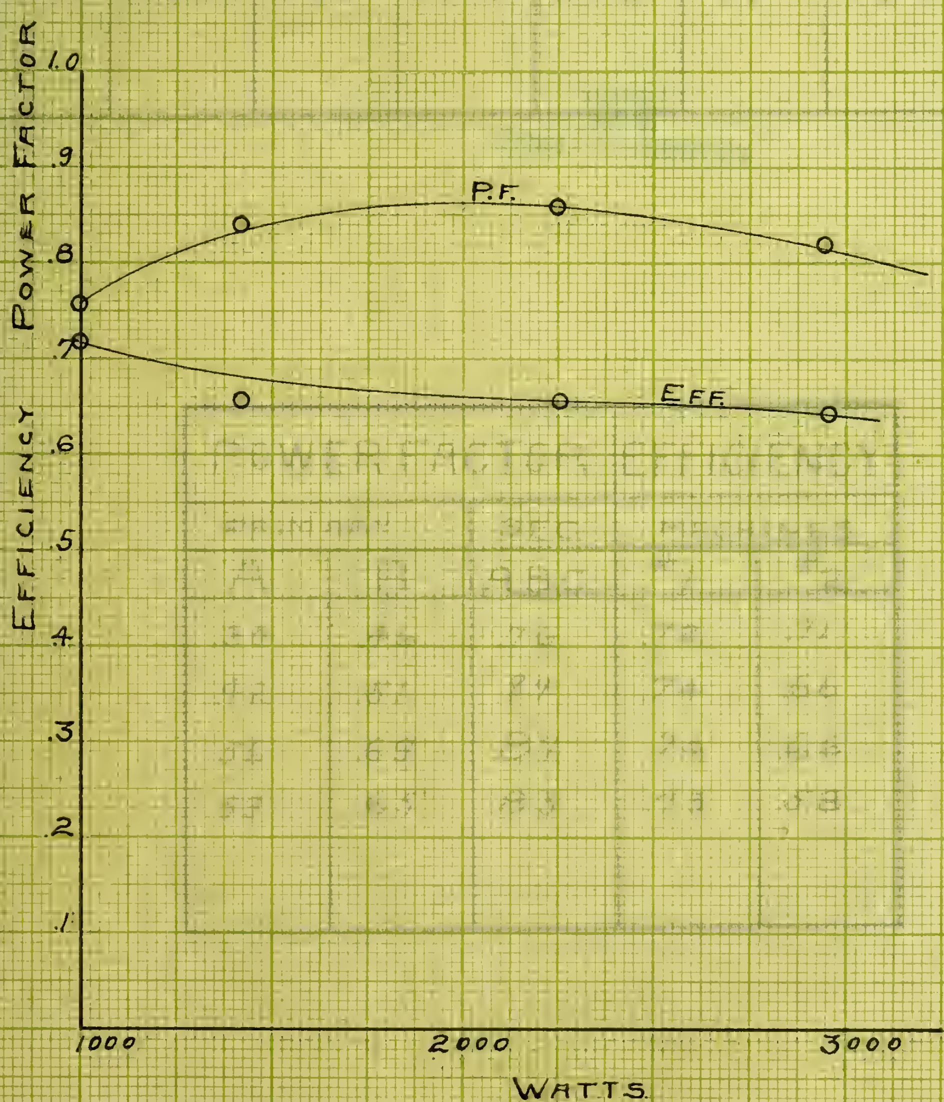


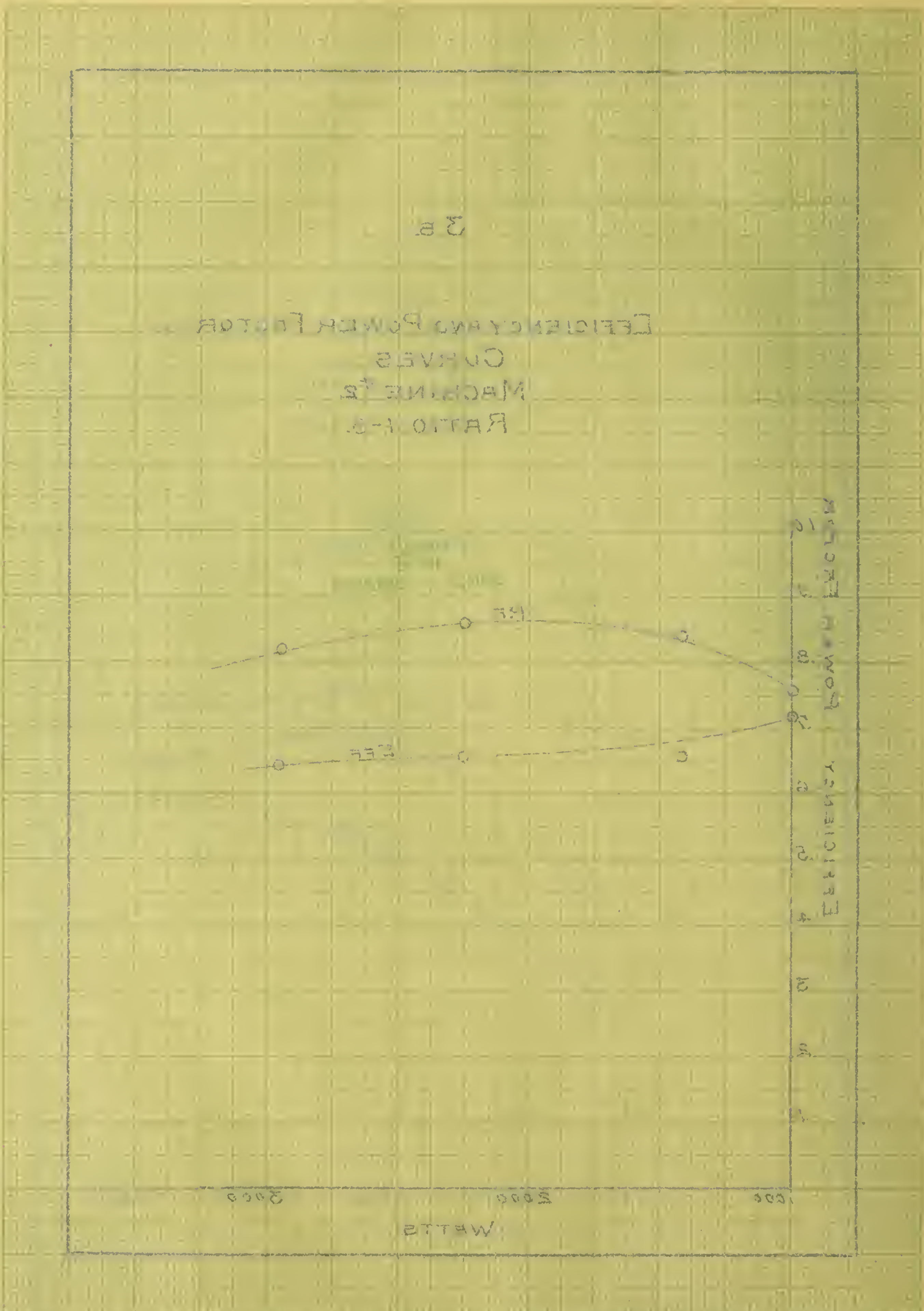


3A
Efficiency and Power Factor
Curves
Machine #1
Ratio 1-3
Eff
P.F. Phase B
P.F. Phase A
Efficiency
Power Factor
Watts
0
1000
2000
3000
4000
5000
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

3 B.

EFFICIENCY AND POWER FACTOR CURVES
MACHINE #2
RATIO 1-3.





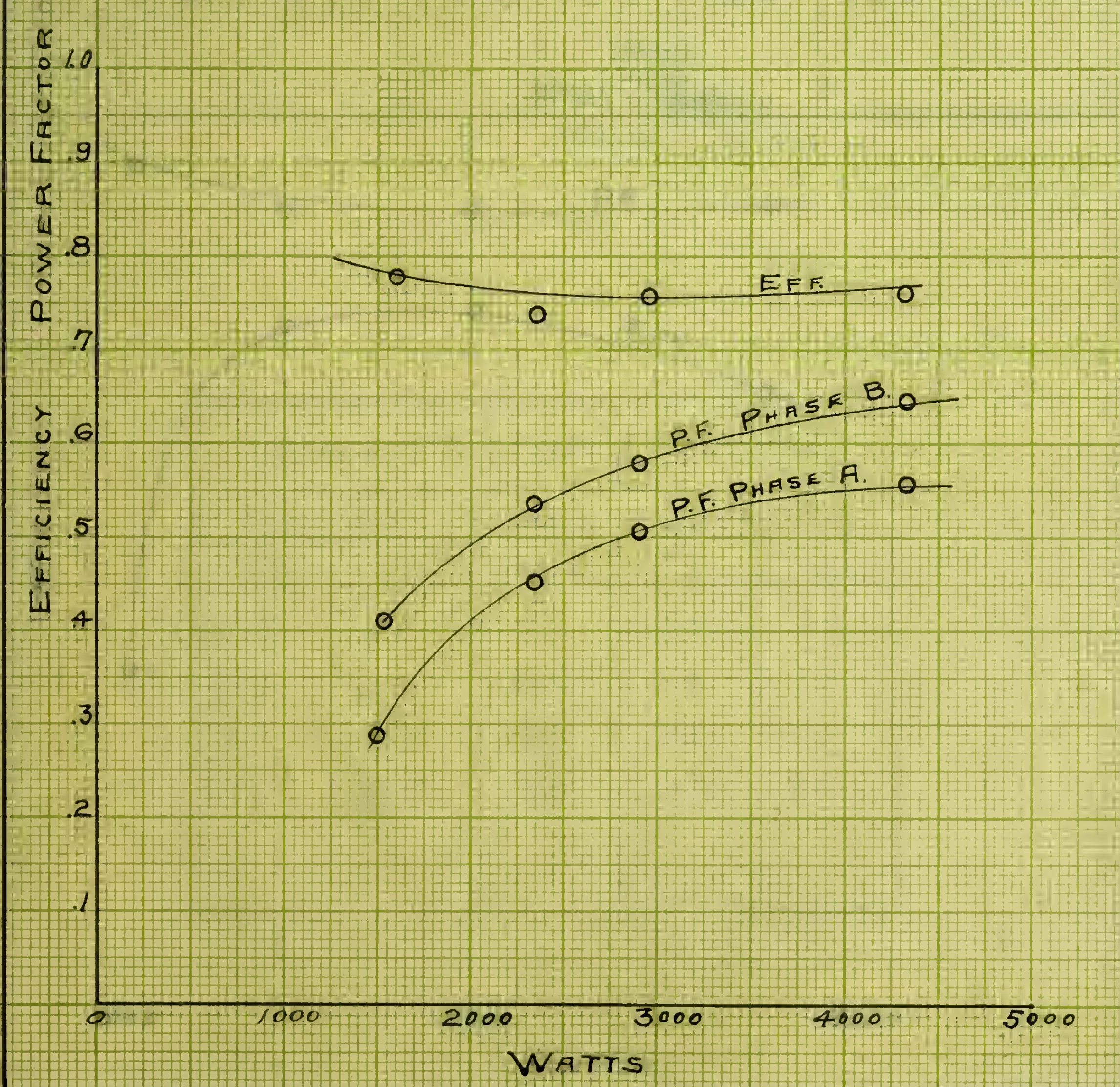
RATIO-1-3.

WATTS INPUT.				AMP.PER.CIR.		VOLTS.	
MACHINES							
A.C.		D.C.		PRIMARY	SECONDARY	PRIMARY	SECONDARY
#1	#2	#1	#2	I	I	V	V
1820	1070	242	760	12.6	14	193	58
2360	1450	296	951	13.5	17	198	58
3700	2270	470	1505	15.5	29	195	54
4720	2950	489	1715	20.3	38	193	53

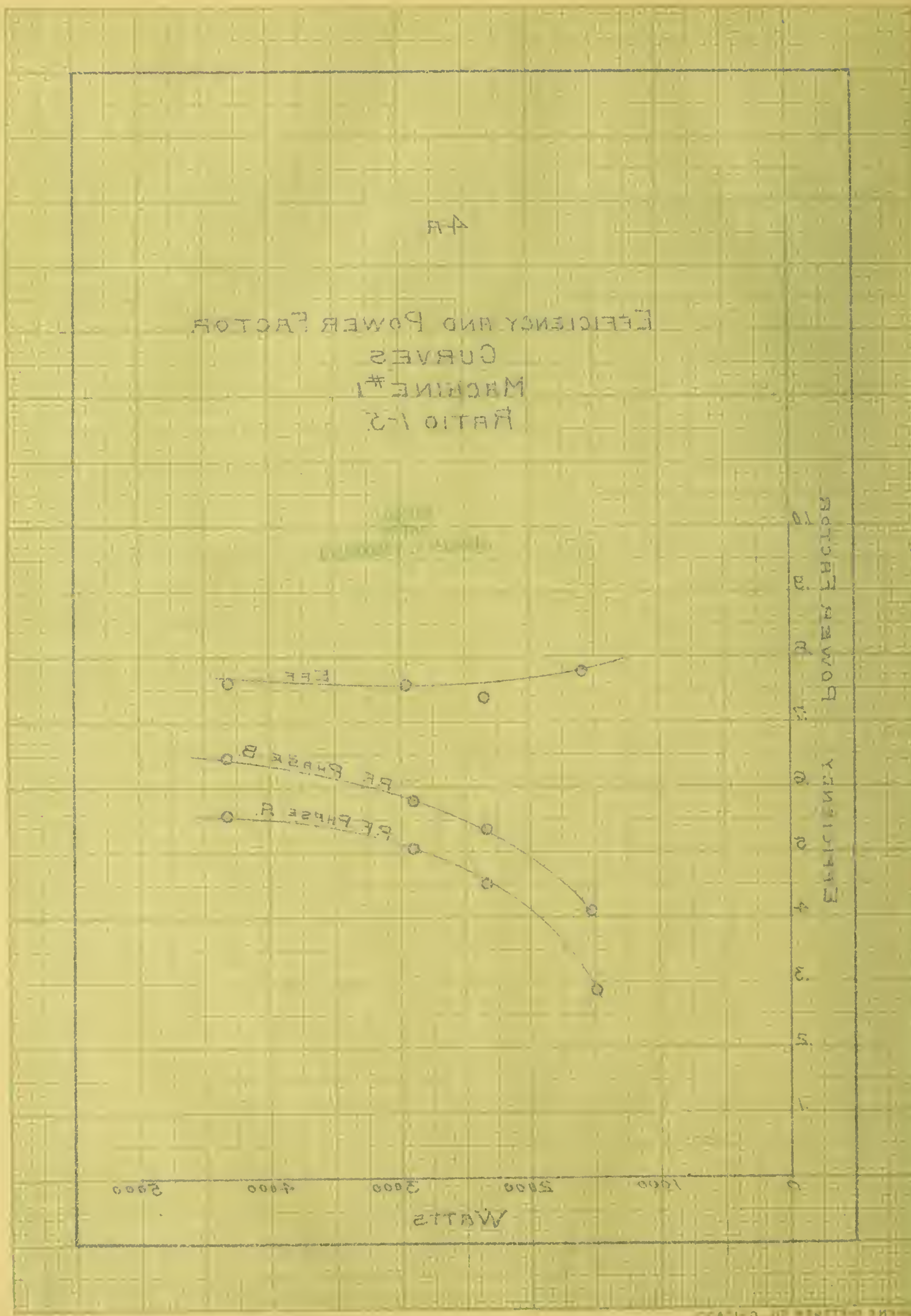
POWER FACTOR			EFFICIENCY	
PRIMARY		SEC.	MACHINES	
A	B	A.B.C.	#1	#2
.30	.46	.76	.72	.71
.42	.51	.84	.74	.66
.56	.69	.87	.74	.66
.59	.65	.83	.73	.58

4A.

EFFICIENCY AND POWER FACTOR CURVES
MACHINE #1
RATIO 1-5

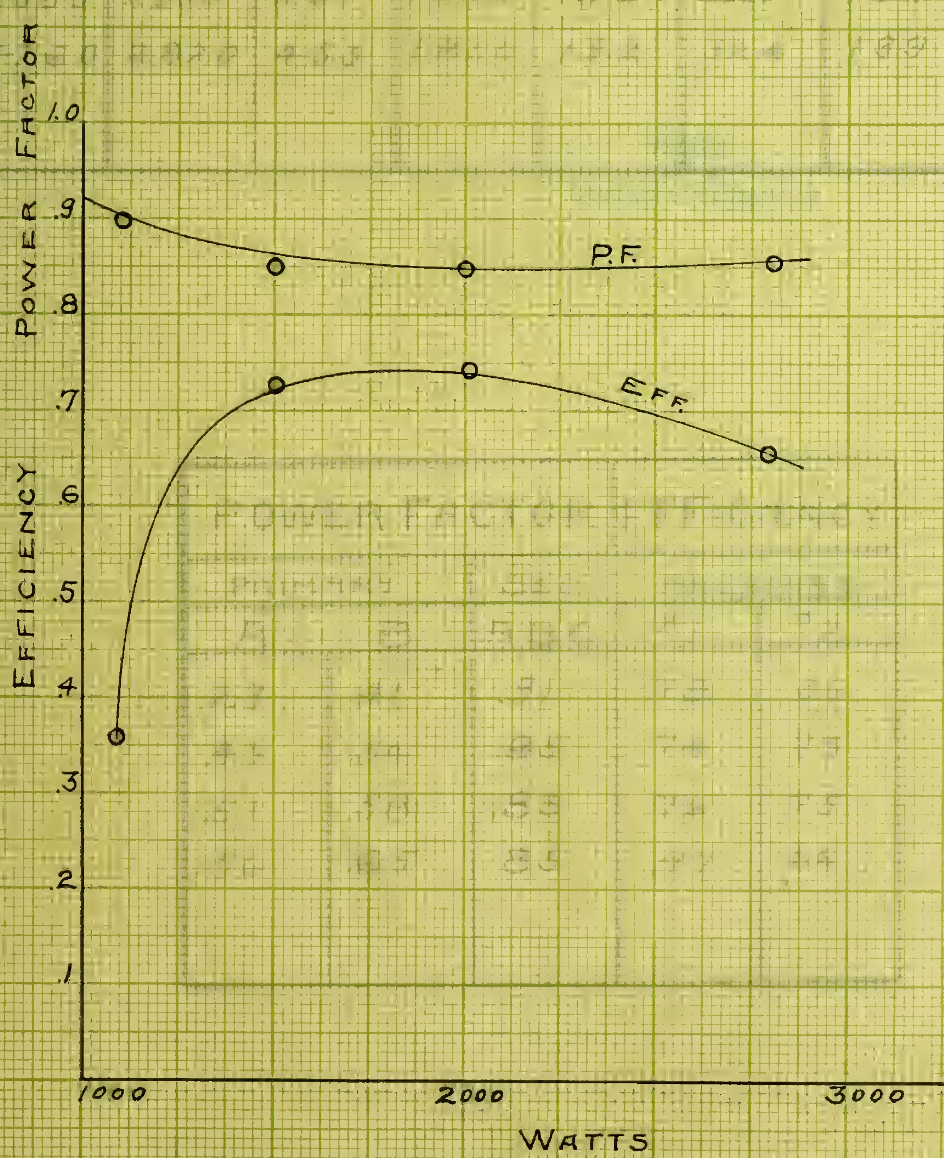


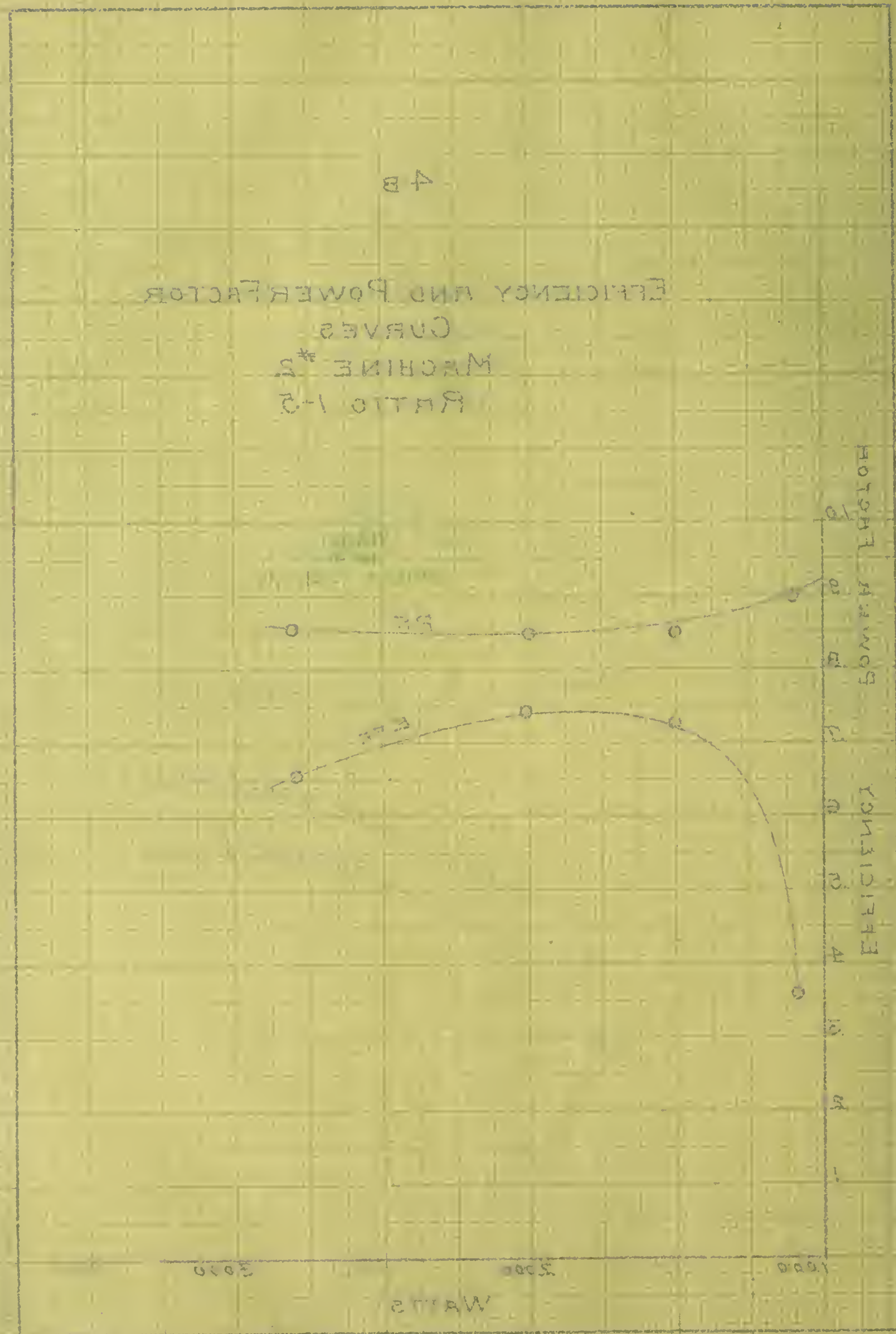
EUGENE DIETZGEN CO., CHICAGO.


4A
Efficiency and Power Factor
Curves
Machine #1
Ratio 1-5
Eff
P.F. Phase B
P.F. Phase A
Efficiency Power Factor
Watts
1000
2000
3000
4000
5000

4 B.

EFFICIENCY AND POWER FACTOR CURVES
MACHINE #2
RATIO 1-5



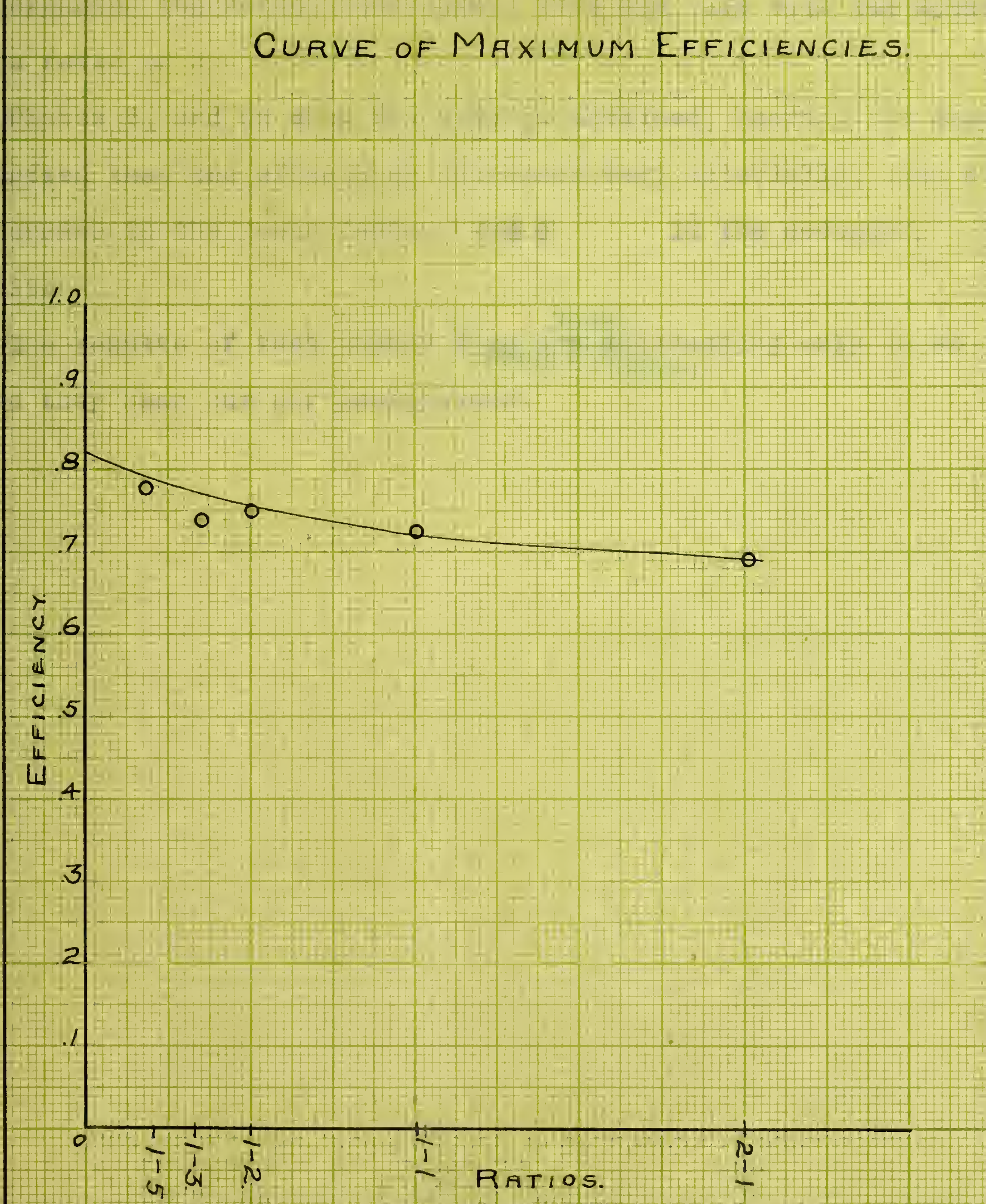

4 B
EFFICIENCY AND POWER FACTOR
CURVES
MACHINE #2
RATIO 1-5
P.F.
EFF.
POWER FACTOR
EFFICIENCY
WATTS
1000
2000
3000

RATIO-1-5

WATTS INPUT				AMP.PER.CIR.		VOLTS	
MACHINES							
A.C		D.C.		PRIMARY	SECONDARY	PRIMARY	SECONDARY
#1	#2	#1	#2	I	I	V	V
1600	1110	137	399	12.3	12.	198	60
2420	1540	235	1130	13.6	18.5	195	59.7
2960	2000	267	1490	15.0	23.	194	58.2
4260	2820	453	1850	18.2	32.4	199	57.5

POWER FACTOR			EFFICIENCY	
PRIMARY		SEC.	MACHINES	
A.	B.	A.B.C.	#1	#2
.29	.41	.91	.78	.36
.45	.54	.85	.74	.73
.51	.58	.85	.76	.75
.56	.65	85	.77	.66

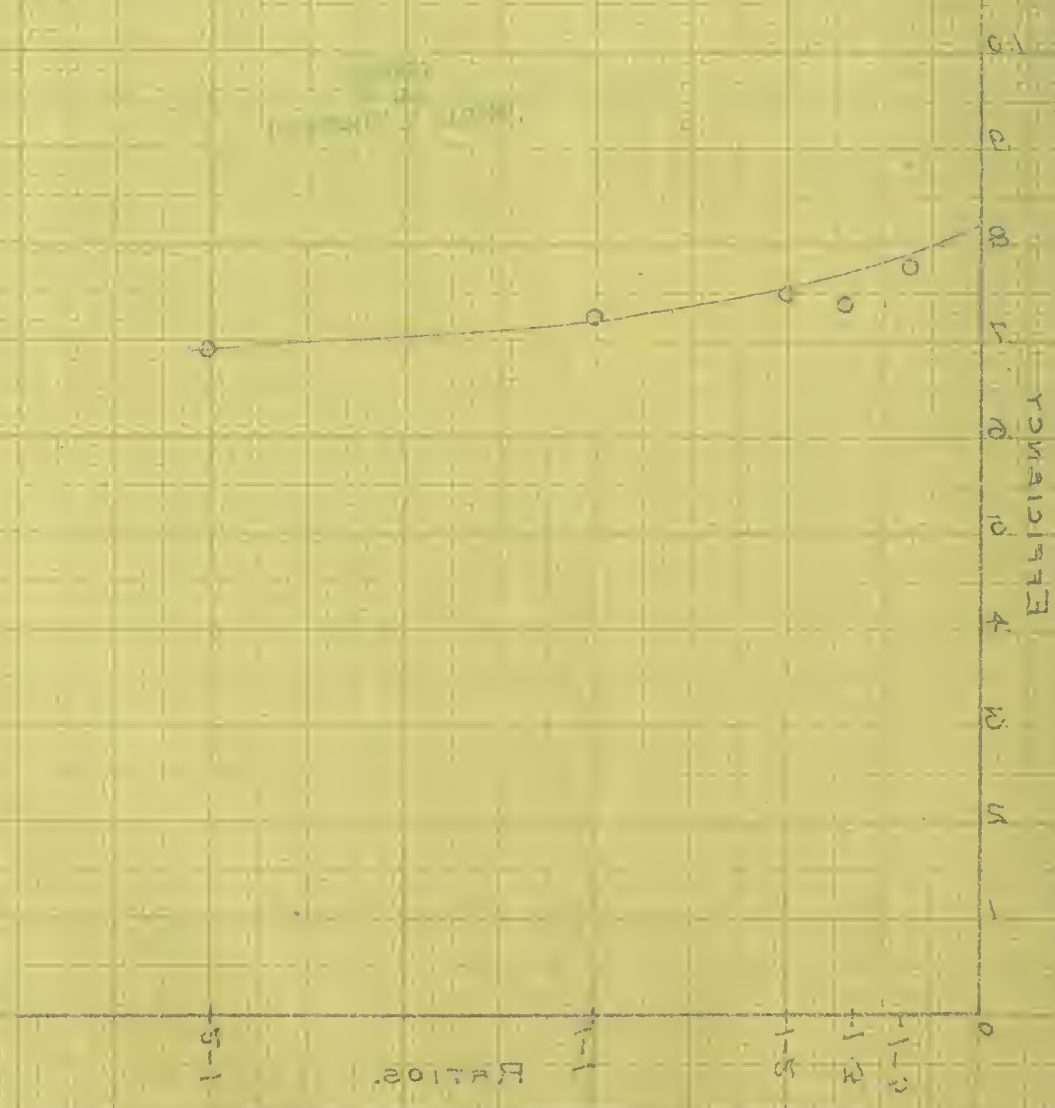
4 c.



EUGENE DIETZGEN CO., CHICAGO.

40.

Curve of Maximum Efficiencies.



TEST 5.

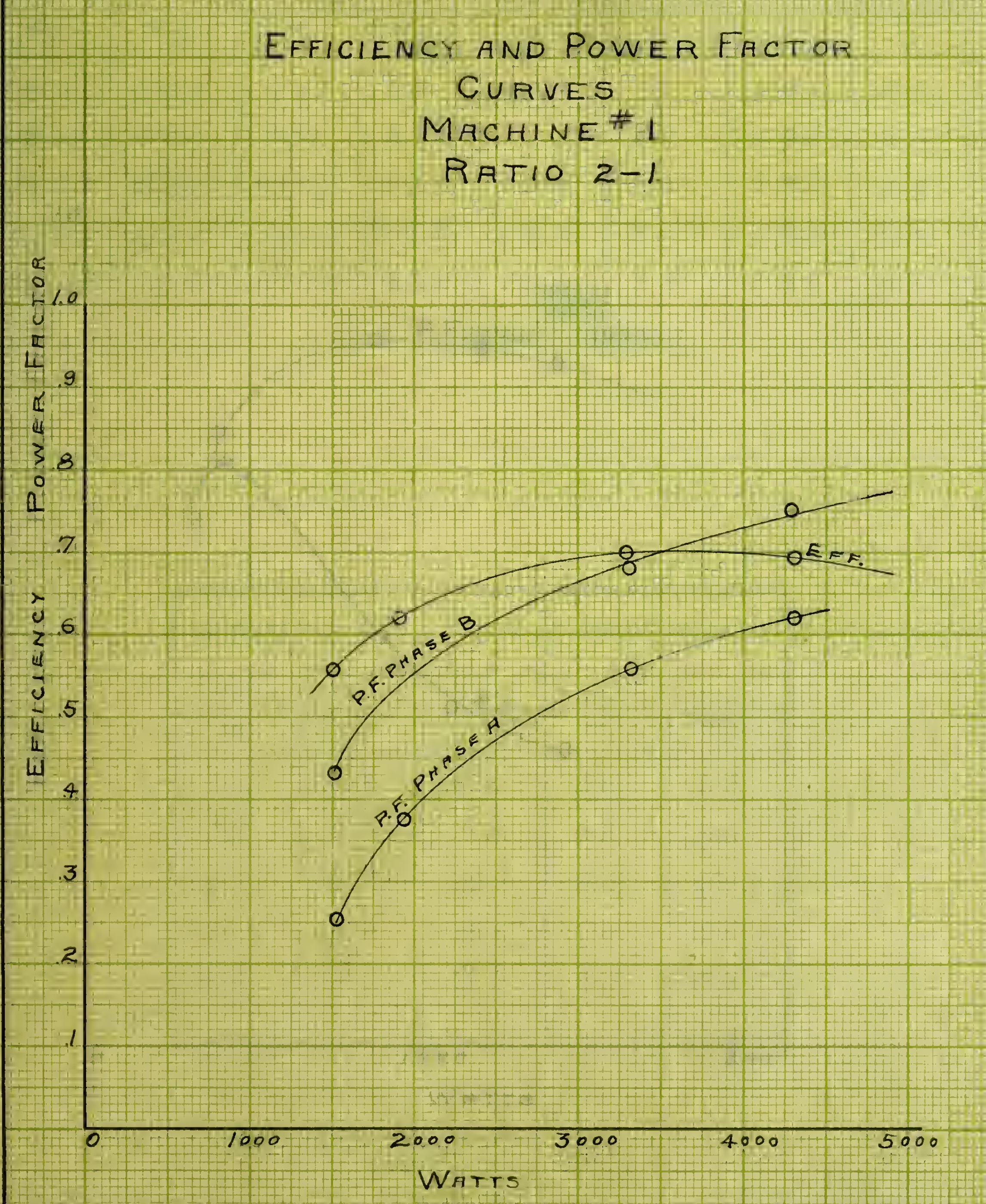
Ratio 2 - 1.

To prove the statements already made as to the desirability of increasing the ratio, test number five was made with the speeds in the ratio of 2 - 1.

Plates 5_a and 5_b show the results obtained, bearing out the assumption that the efficiency decreases very materially, even with an increase in the power factor $\cos \phi$ in the secondary circuit.

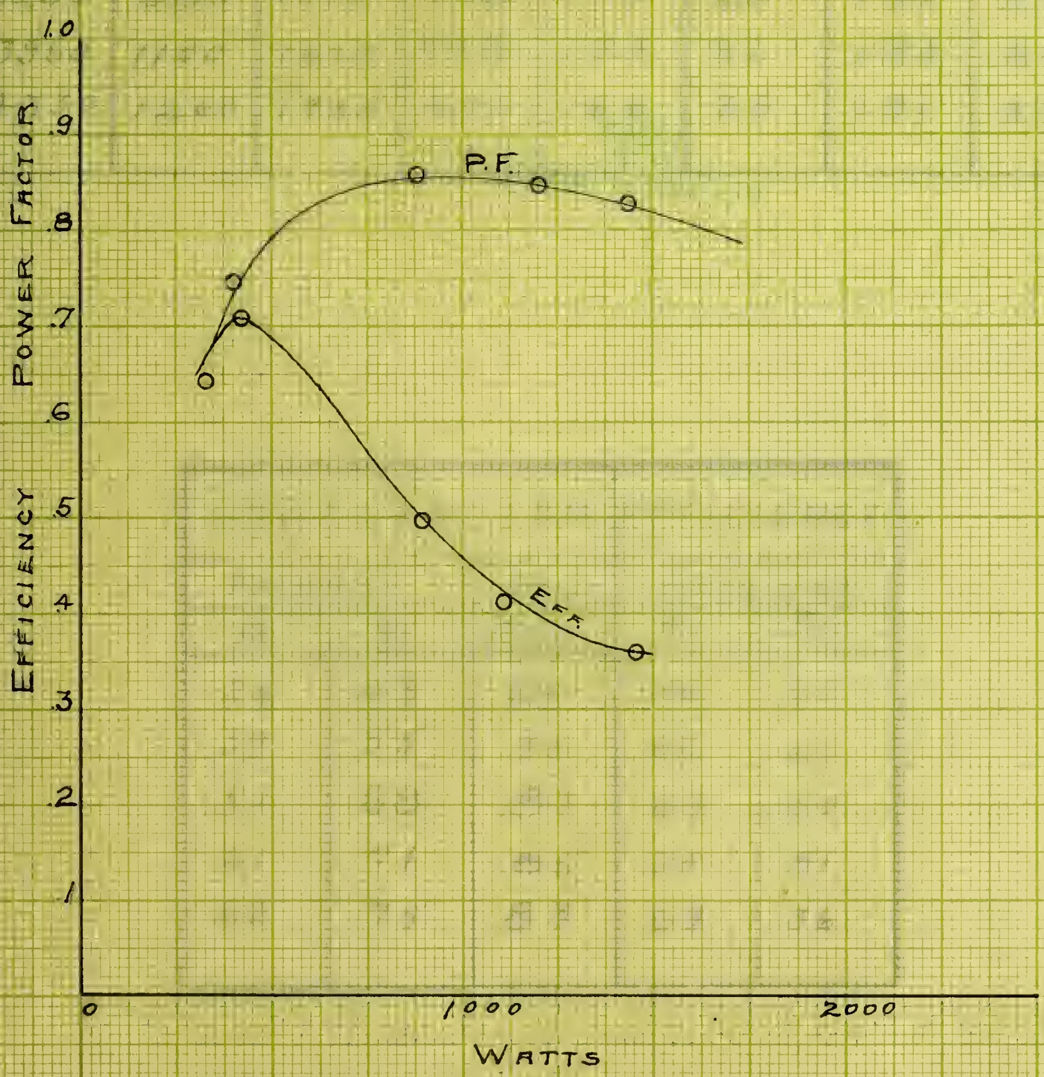
The results of test number five are interesting only in so far as they bear out our assumptions.

5A

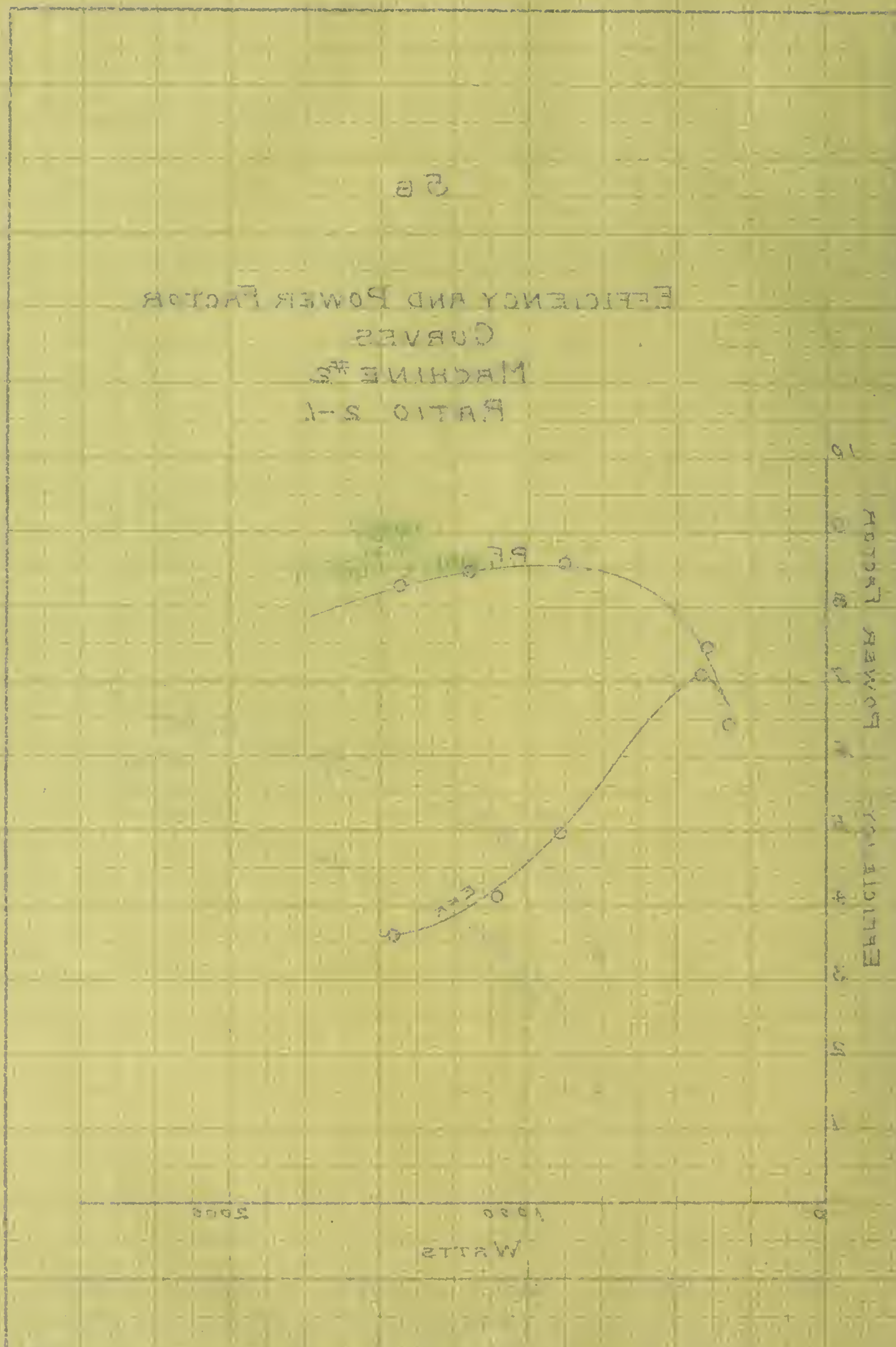

EFFICIENCY AND POWER FACTOR
CURVES
MACHINE # 1
RATIO 2-1
EFFICIENCY POWER FACTOR
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
EFF.
P.F. PHASE B
P.F. PHASE A
0
1000
2000
3000
4000
5000
WATTS

5 B.

EFFICIENCY AND POWER FACTOR CURVES
MACHINE #2.
RATIO 2-1.



EUGENE DIETZGEN CO., CHICAGO.


56
Efficiency and Power Factor
Curves
Machine #2
Ratio 2-1
P.F.
Eff.
Efficiency Power Factor
1
2
3
4
5
6
7
8
9
10
0
1000
2000
Watts

RATIO-2-1

WATTS INPUT				AMP.PER.CIR		VOLTS	
MACHINES							
A.C.		D.C.		PRIMARY	SECONDARY	PRIMARY	SECONDARY
#1	#2	#1	#2	I	I	V	V
1417	325	469	201	10.2	11	204	24
1820	400	731	264	10.5	13	190	22
3290	885	1370	438	13.5	25	190	24
3960	1100	1675	448	15.4	31	190	24
4330	1260	1735	450	16.6	35	191	25

POWER FACTOR			EFFICIENCY	
PRIMARY		SEC.	MACHINES	
A	B	A.B.C.	#1	#2
.26	.43	.64	.56	.62
.39	.55	.75	.62	.66
.57	.68	.87	.69	.50
.61	71	.85	.70	.41
.62	.75	.83	.69	.36

PART [illegible]

A study of the foregoing tests showed that the power factor of both the primary and secondary circuits was very low. To improve the power factor promised to improve the efficiency and therefore, to increase the output of both machines.

To improve the power factor, or compensate for the wattless component of the current, it was necessary to place capacity in the circuit. Bridged across the three phase secondary circuit were placed three step up transformers with secondaries connected to condensers. All the available capacity proved to be insufficient to materially affect the operation. Approximately [illegible] micro-farads were placed across each phase, calculations showed that 140 micro-farads were necessary to produce resonance.

Test number six shows the results obtained with capacity connected as described, or as shown in diagram of connections number three.

Comparing the results obtained as they are graphically plotted on plates #[illegible] and #[illegible] with the curves obtained for the same ratio without capacity, we obtain the table below. Plates #[illegible] and #[illegible] show the results obtained for the ratio 1 - 2 the same capacity being used as was used in ratio 1 - 1.

TABLE

Ratio 1 - 1

	Motor #1	Motor #2
Power Factor	slightly increased	slightly increased
Efficiency	decreased	increased

Ratio 1 - 2	Motor #1	Motor #2
Power factor	increased	decreased
Efficiency	decreased	decreased

Table comparing results obtained with capacity with those obtained without capacity.

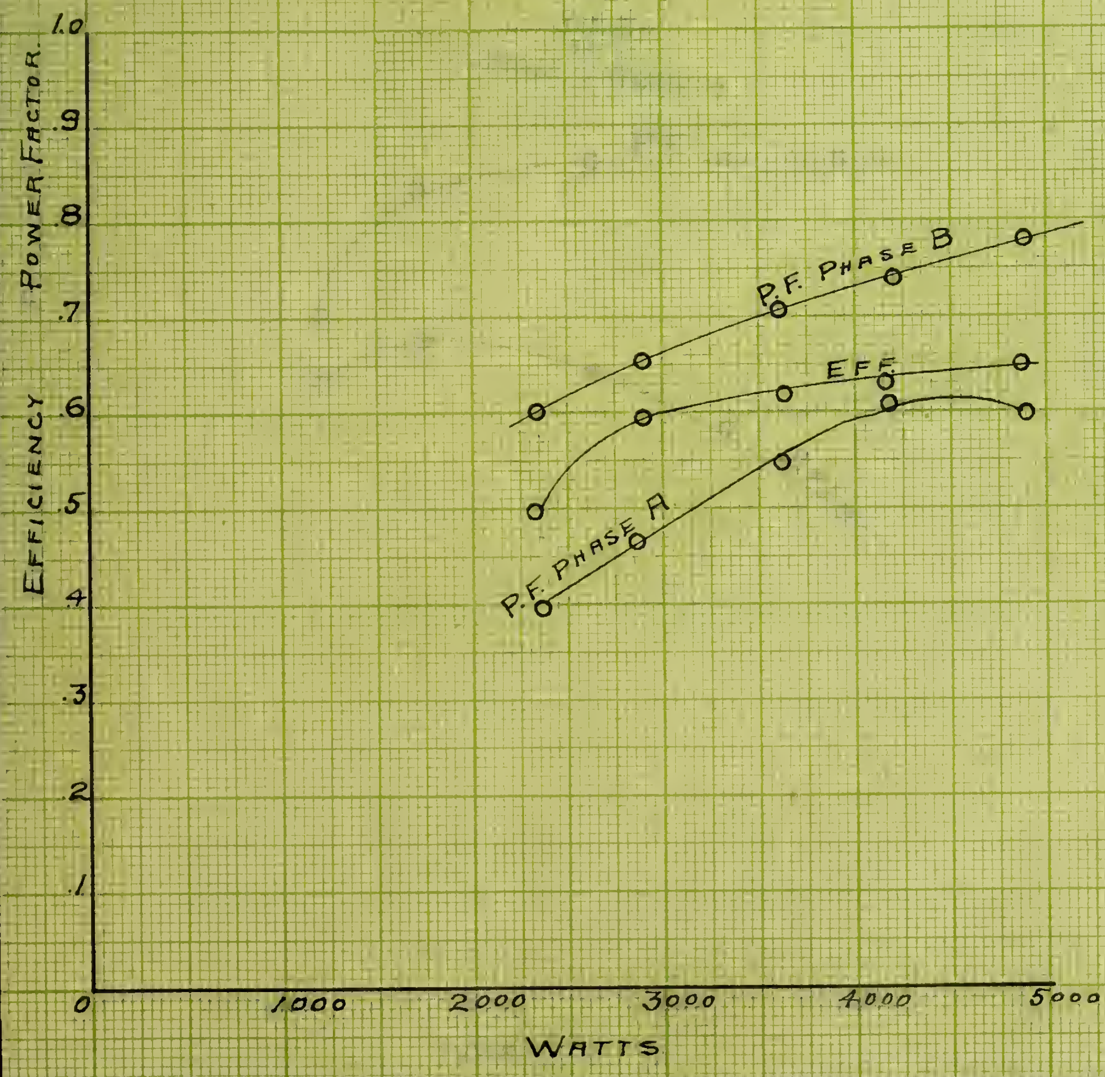
The slight increase in the power factor noted above is directly at the expense of efficiency, a result highly disadvantageous. Thus one may be led to believe that the introduction of capacity has far from produced the desired results.

It may be stated that throughout the history of induction motors, leaving out Mr. Alexander Heylands compensated motor, that any device for increasing the power factor has decreased the efficiency.

The theoretical gain in power obtained by the addition of capacity in the secondary circuit, is more than off-set by the losses in the three transformers.

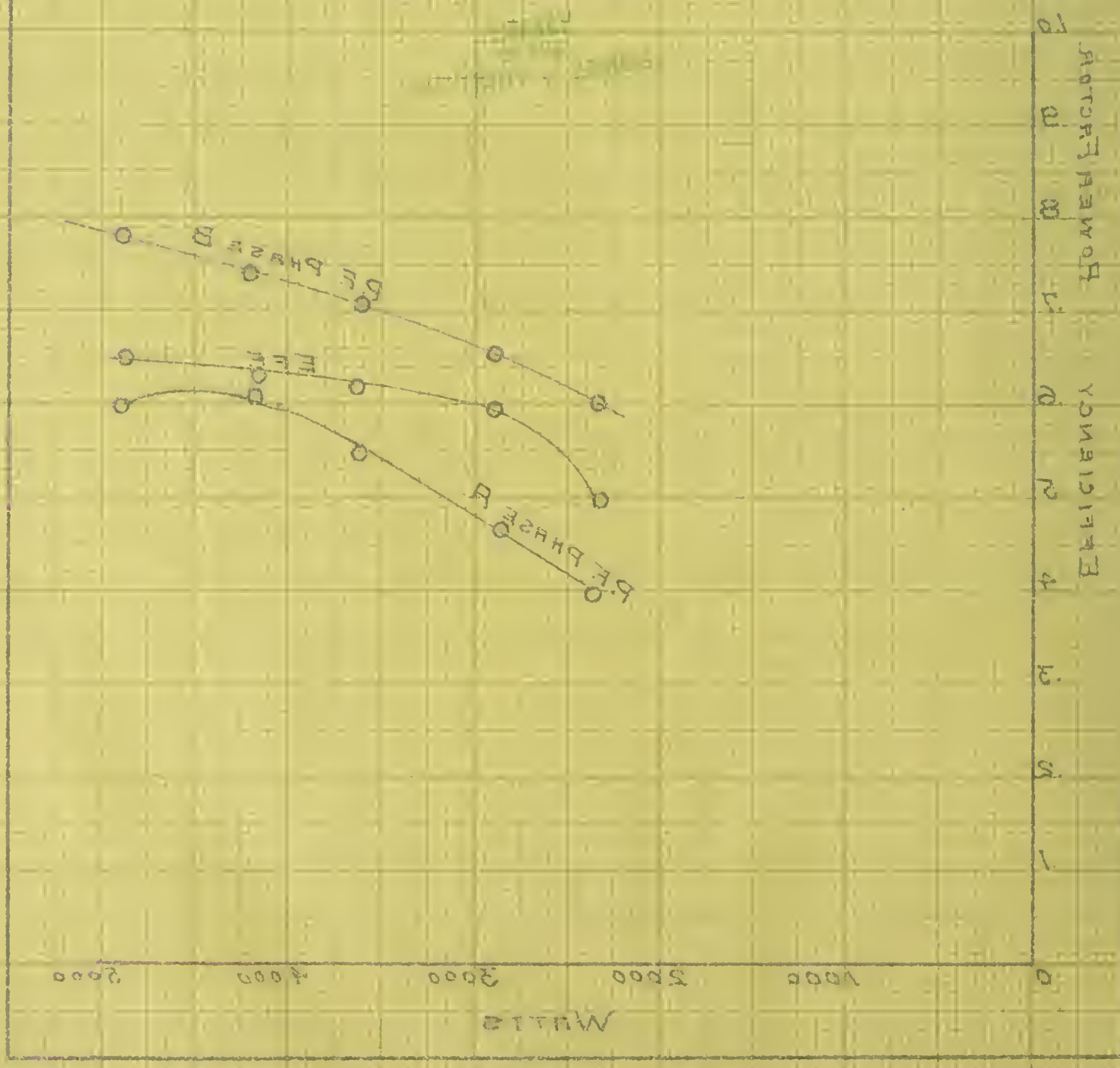
6 A.

EFFICIENCY AND POWER FACTOR
CURVES
MACHINE #1.
RATIO 1-1.
CAPACITY IN SECONDARY
CIRCUIT



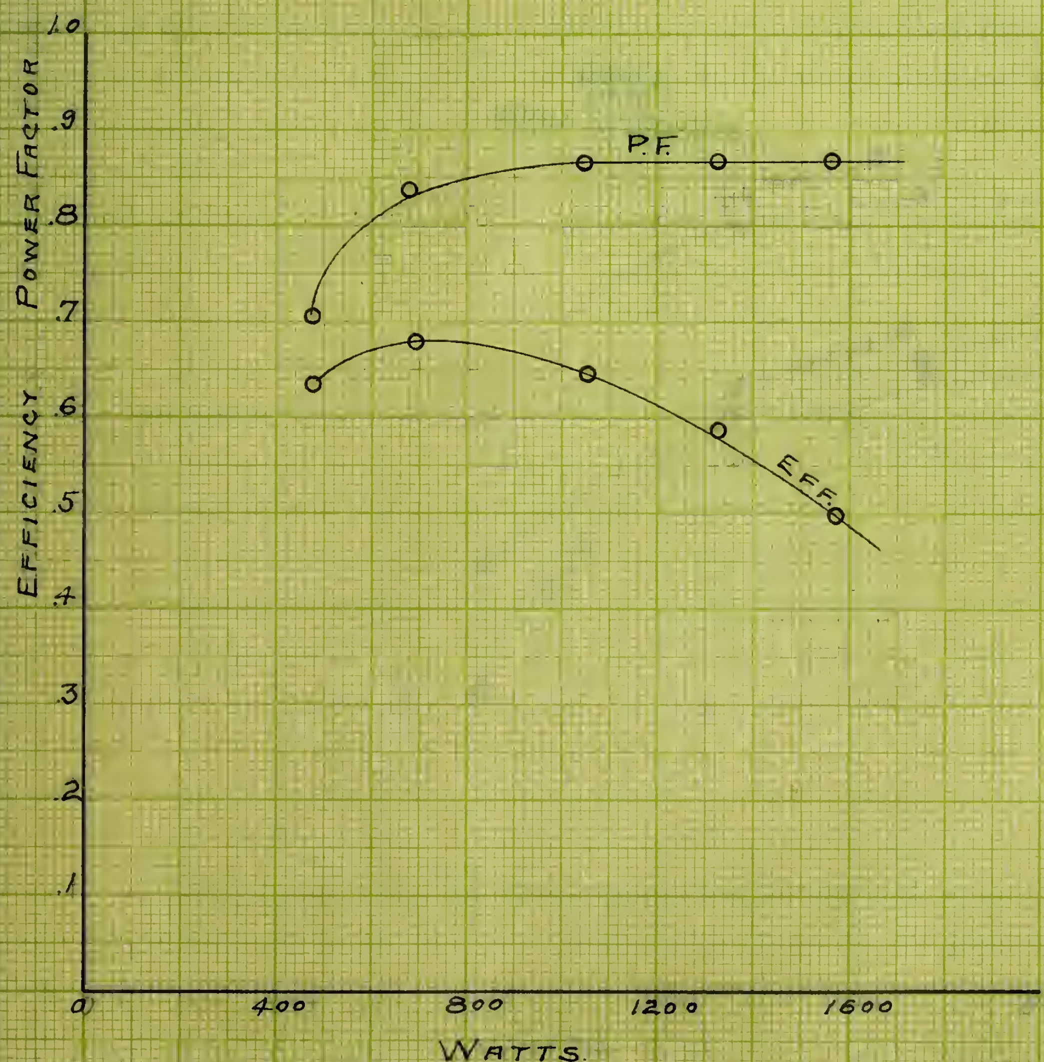
6 A.

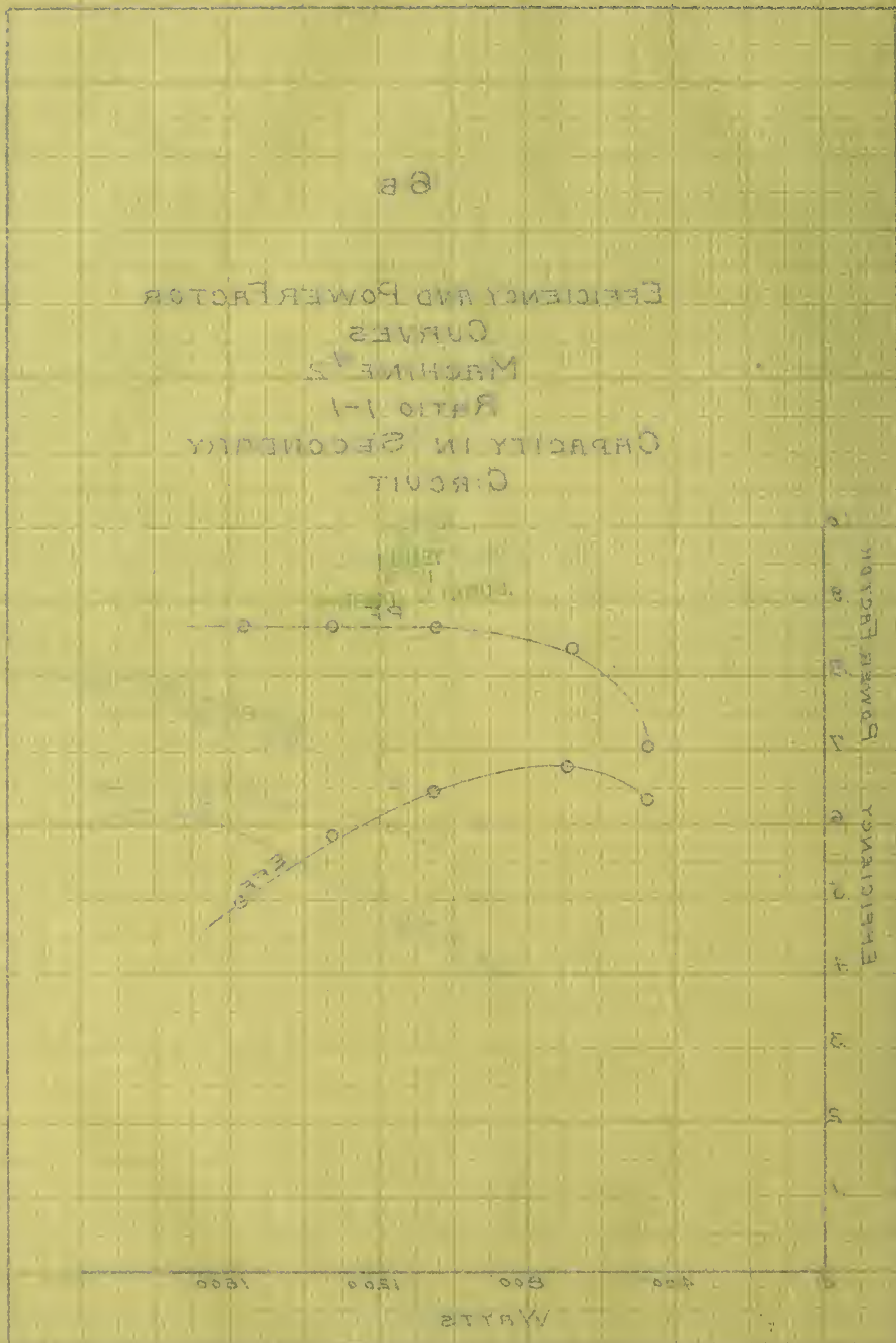
Efficiency and Power Factor
Curves
Machine #1.
Ratio 1-1.
Capacity in Secondary
Circuit



6 B.

EFFICIENCY AND POWER FACTOR CURVES
MACHINE #2
RATIO 1-1
CAPACITY IN SECONDARY CIRCUIT.

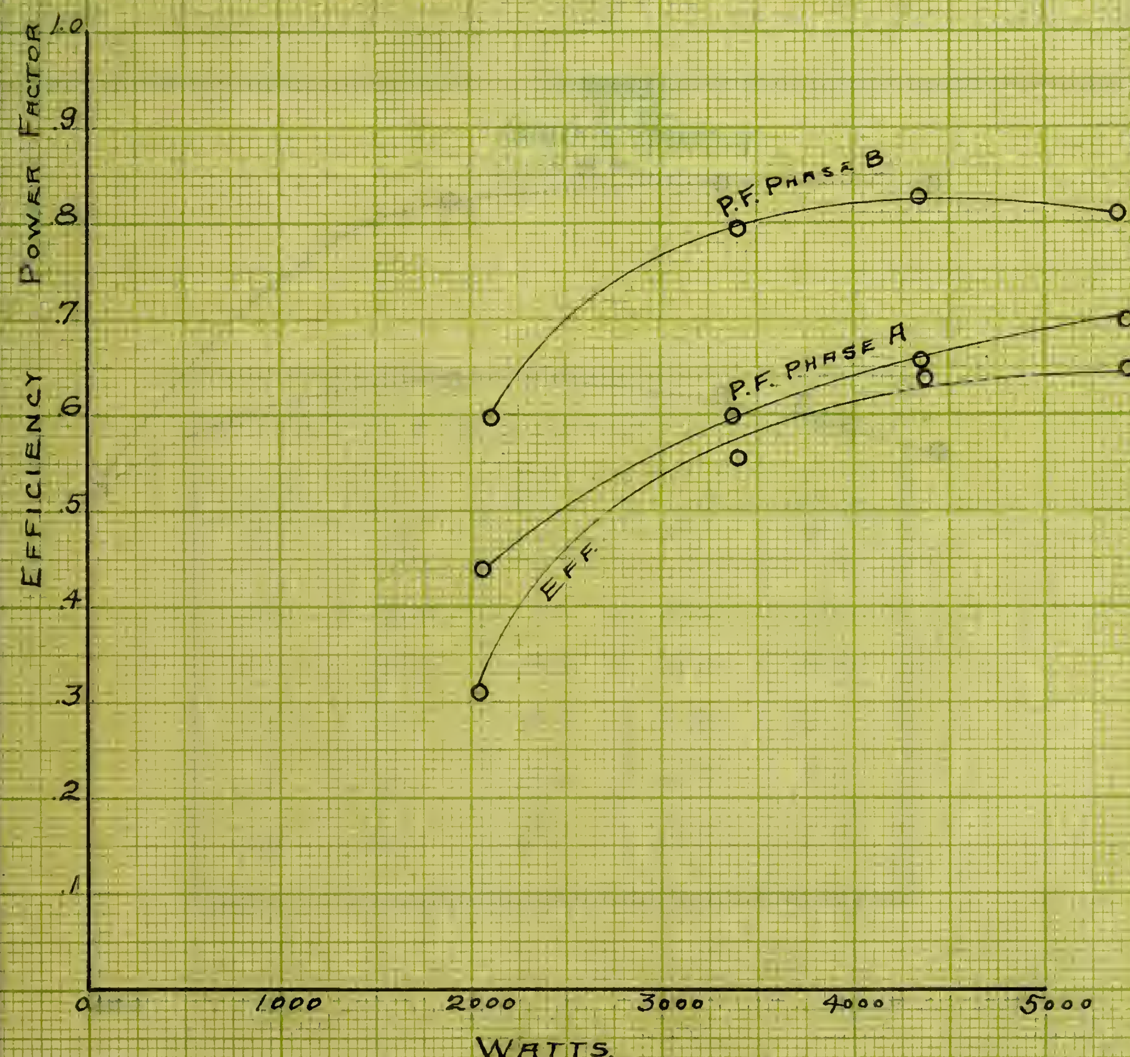


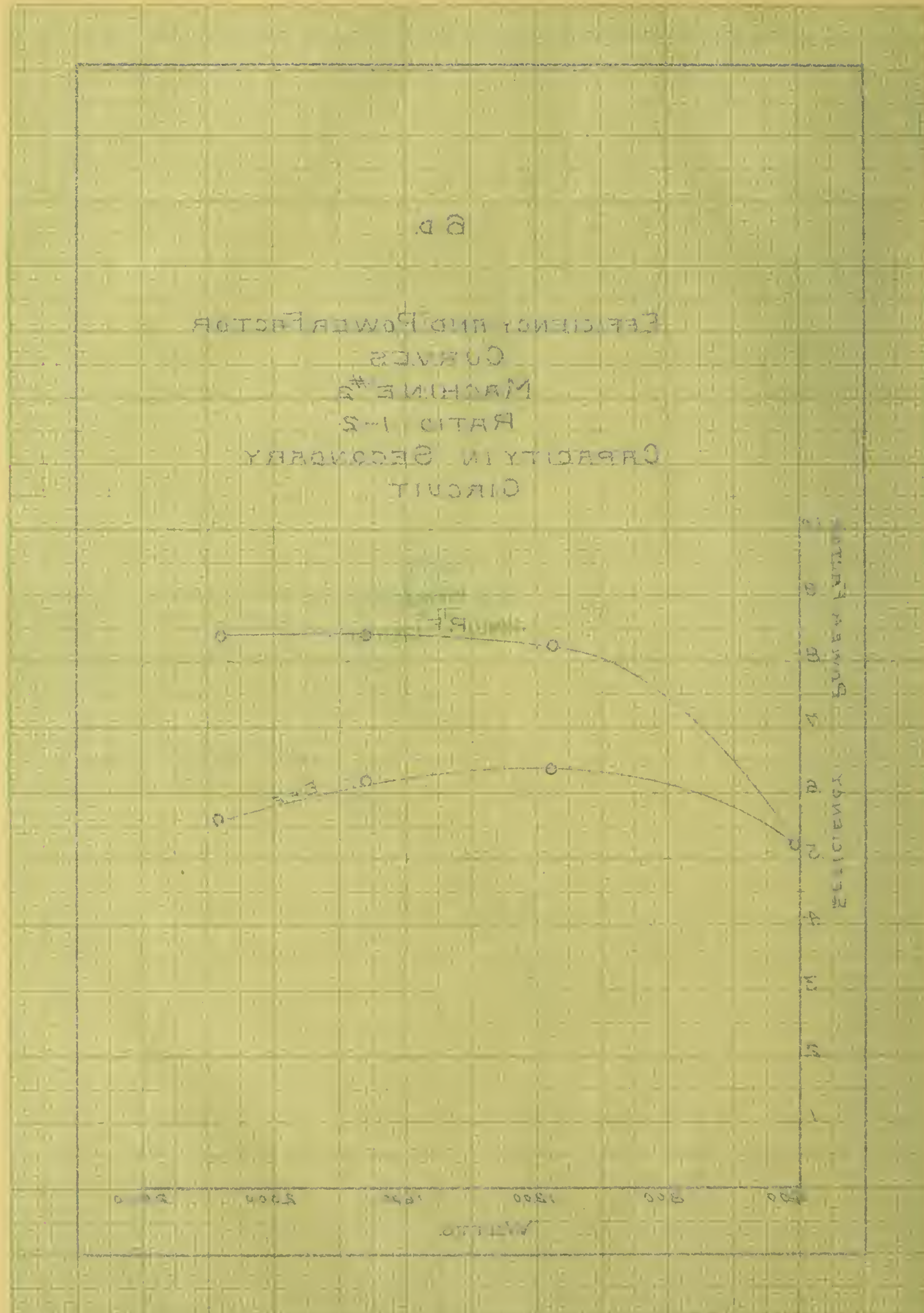


6 B
Efficiency and Power Factor Curves
Machine 2
Ratio 1-1
Capacity in Secondary Circuit
PF
Eff
Efficiency Power Factor
Watts
1600
1200
800
400

6 C.

EFFICIENCY AND POWER FACTOR
CURVES
MACHINE #1
RATIO 1–2
CAPACITY IN SECONDARY
CIRCUIT




6 D.
Efficiency and Power Factor
Curves
Machine #2
Ratio 1-2
Capacity in Secondary
Circuit
P.F.
Eff.
Power Factor
Efficiency
Watts

RATIO-1-1.

CAPACITY IN SECONDARY CIRCUIT.

WATTS INPUT.				AMP. PER. CIR.		VOLTS.	
MACHINES				PRIMARY	SECONDARY	PRIMARY	SECONDARY
A.C.		D.C.					
#1	#2	#1	#2	I	I	V	V
2420	475	735	306	13	12	194	34
2960	725	1030	495	14	16	196	34
3600	1050	1198	680	15	21.7	194	34
4240	1315	1363	775	16.5	27.5	192	33
4880	1570	1599	783	19.	34.3	192	32

POWER FACTOR			EFFICIENCY	
PRIMARY		SEC.	MACHINES	
A	B	A.B.C.	#1	#2
.40	.60	.71	.50	.64
.47	.66	.84	.60	.68
.55	.71	.87	.62	.65
.61	.74	.87	.63	.59
.60	.78	.87	.65	.50

RATIO-1-2
CAPACITY IN SECONDARY CIRCUIT.

WATTS INPUT.				AMP. PER. CIR.		VOLTS.	
MACHINES							
A.C.		D.C.		PRIMARY	SECONDARY	PRIMARY	SECONDARY
#1	#2	#1	#2	I	I	V	V
2120	425	465	224	11	10.	190	44
3380	1150	761	741	12.8	17.7	194	44
4360	1710	970	1070	15.3	25.3	194	43
5460	2230	1185	1260	18.75	37.	193	42

POWER FACTOR			EFFICIENCY	
PRIMARY		SEC.	MACHINES	
A.	B.	A.B.C.	#1	#2
.44	.60	.54	.31	.53
.60	.81	.83	.56	.65
.66	.83	.84	.64	.63
.70	.80	.84	.64	.57

Performance of Single Induction Motors.

The results obtained with the machines operated in concatenation would be meaningless without data showing the performance of the motors running on voltage and current for which they were designed. The operation of the motors under the latter conditions can be studied more closely by the use of the stray power method of testing than by the brake tests with all their sources of error.

Alexander W. Heyland has devised the Circle Diagram for the study of the induction motors, this, with modifications used by other authorities, is the method used herein.

The data necessary for the construction of the Circle Diagram is the no load characteristic and short circuit characteristic. To obtain the no load curves, the machine is run light on the proper frequency current and the voltage impressed is varied from a value somewhat above normal to a value just sufficient to operate the motor. Readings of amperes, watts and volts input per phase are taken and plotted, using volts as abscissa and amperes and watts as ordinates.

The short circuit curves are obtained by plotting readings of amperes and watts per phase as ordinates and volts per phase as abscissa when the secondary is blocked and the voltage varied from zero to a value sufficient to cause 150% of full load current to flow.

From these sets of curves the exciting current and the full voltage blocked secondary current is obtained.

Referring to curve sheet marked "Circle Diagram Machine #1"

the following method of procedure is followed:

Draw O C = magnetizing current at full voltage found from no load curves.

Draw O I = short circuit current or ideal current at full voltage

From the relation $\frac{O\,C}{O\,R} = \sigma$ leakage factor, and max. cosine $\phi = \frac{1}{2\sigma+1}$ determine cosine ϕ

Draw O A at right angles to O G the horizontal axis.

Draw O P making an angle ϕ_a with O A.

Draw semi circle, center in O G, tangent to O P and passing through C and F.

Draw O I = [illegible] and join [illegible] I.

Assume a point H at about 100% over load

Current = length O H and draw H I.

Calculate [illegible] I = I^2 R of primary and lay off [illegible] I to scale of watts, remembering that each vertical as well as horizontal division equals current to some scale, say two amperes per division. Then if the normal voltage of the machine is 110, each division corresponds to 2 x 110 = 220 watts.

From I draw I K parallel to O G until it intersects [illegible] at K. Through K, C, F draw semi circle.

Tangent to D F at [illegible] and passing through C draw another semi circle.

On the vertical axis lay off O A = 100% power factor and describe arc A B and extend.

Assume point P on curve and draw P F. Now, for any input O P equals current; perpendicular distance [illegible] to O G equals com-

ponent of current, and perpendicular distance from [illegible] to A equals wattless component.

Label intersection of P E with [illegible] as [illegible] and draw [illegible] perpendicular to O C and label its intersection with C E as V.

Label intersection of P E with O B M as S and draw S W perpendicular to C E.

Now R V equals input - $I^2 R$ loss in primary.

R V equals R Y - V Y equals input - $I^2 R$ loss in primary - core loss.

Now S W equals input in secondary - $I^2 R$ loss for secondary.

$\therefore$ S W equals theoretical output of secondary in synchronous watts.

$$\frac{S\,W}{P\,L} = \frac{\text{Output}}{\text{Input}} = \text{Efficiency}$$

$$\frac{R\,V - S\,W}{R\,V} = \frac{I^2\,R\ \text{Secondary}}{\text{Input}} = \text{slip}$$

$$\text{Cos}\ \phi = \text{for loading } P = \frac{O\,N}{O\,A}$$

A further correction is used on this diagram to compensate for the primary (I R) drop.

The line C E is drawn so as to make an angle α with the horizontal, such that $\tan \alpha = \frac{O\,C \times R}{E}$ Where R and E are the primary resistance and voltage.

From the above relations the data showing the performance of the machine when operated as single induction motors at normal voltage, current and frequency has been derived, tabulated and

plotted herewith.

The "circle diagram" for each machine are worked out and the results obtained are tabulated and curves plotted.

Comparing the results obtained for the single motors with those for the machines in concateration gives one an impression that the latter method of connection is not a commercial success. The reasons for the apparent poor results obtained with motors in concatenation will be discussed under conclusions.

As a means of comparing the theoretical performance of machine number one when operated alone and in tandem, the third circle diagram herewith was drawn.

With the normal connections for the motors in cascade the short circuit data, as well as the no load data were taken. From the curves thus obtained the data for the circle diagram with the machines in tandem was plotted. The calculated data is tabulated and curves plotted the same as for the single motors.

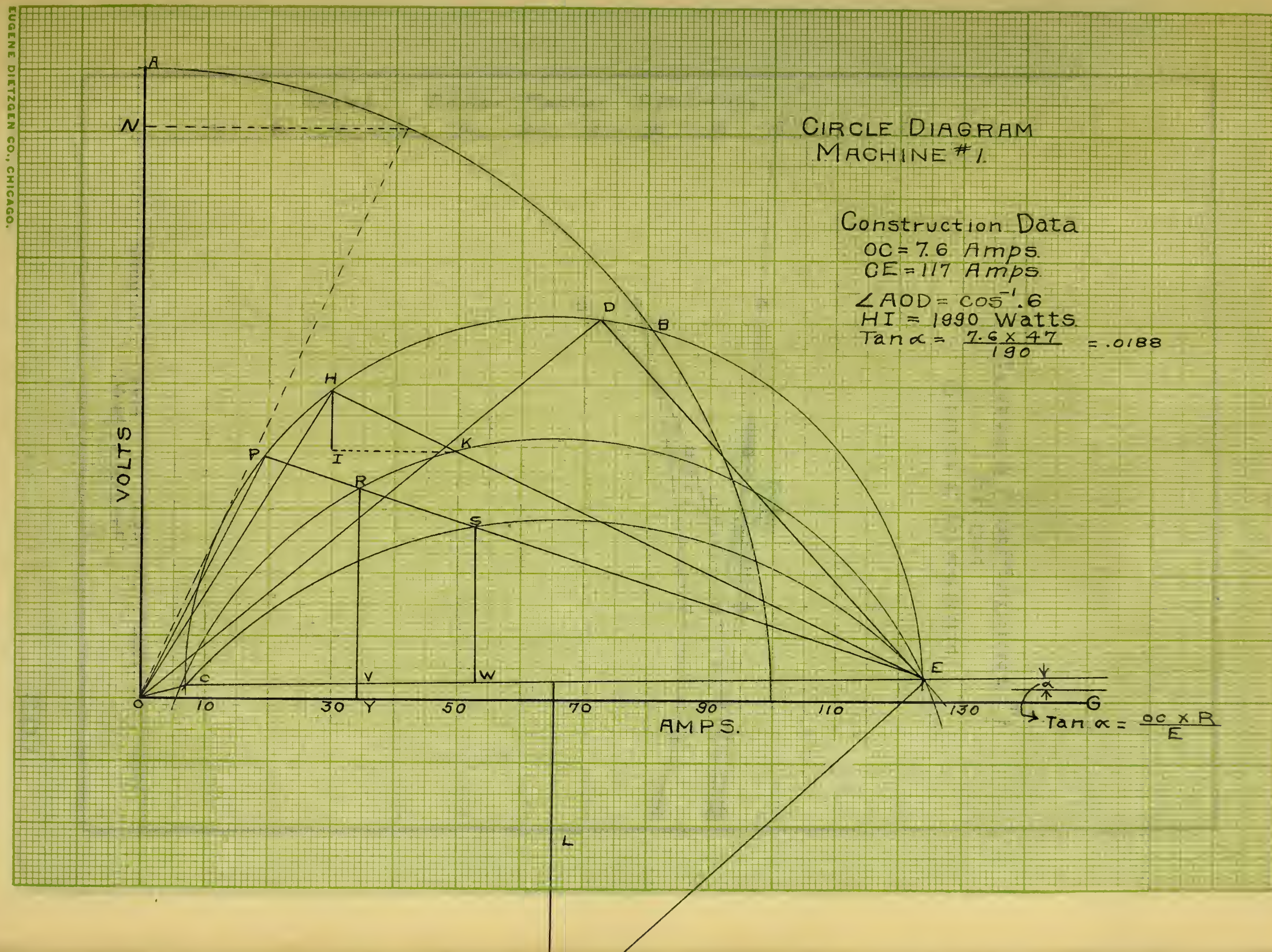
In comparing the operating data thus obtained with the data from the first circle diagram it must be remembered that the only condition changed changed are the introduction of resistance and inductance into the secondary circuit of machine number one.

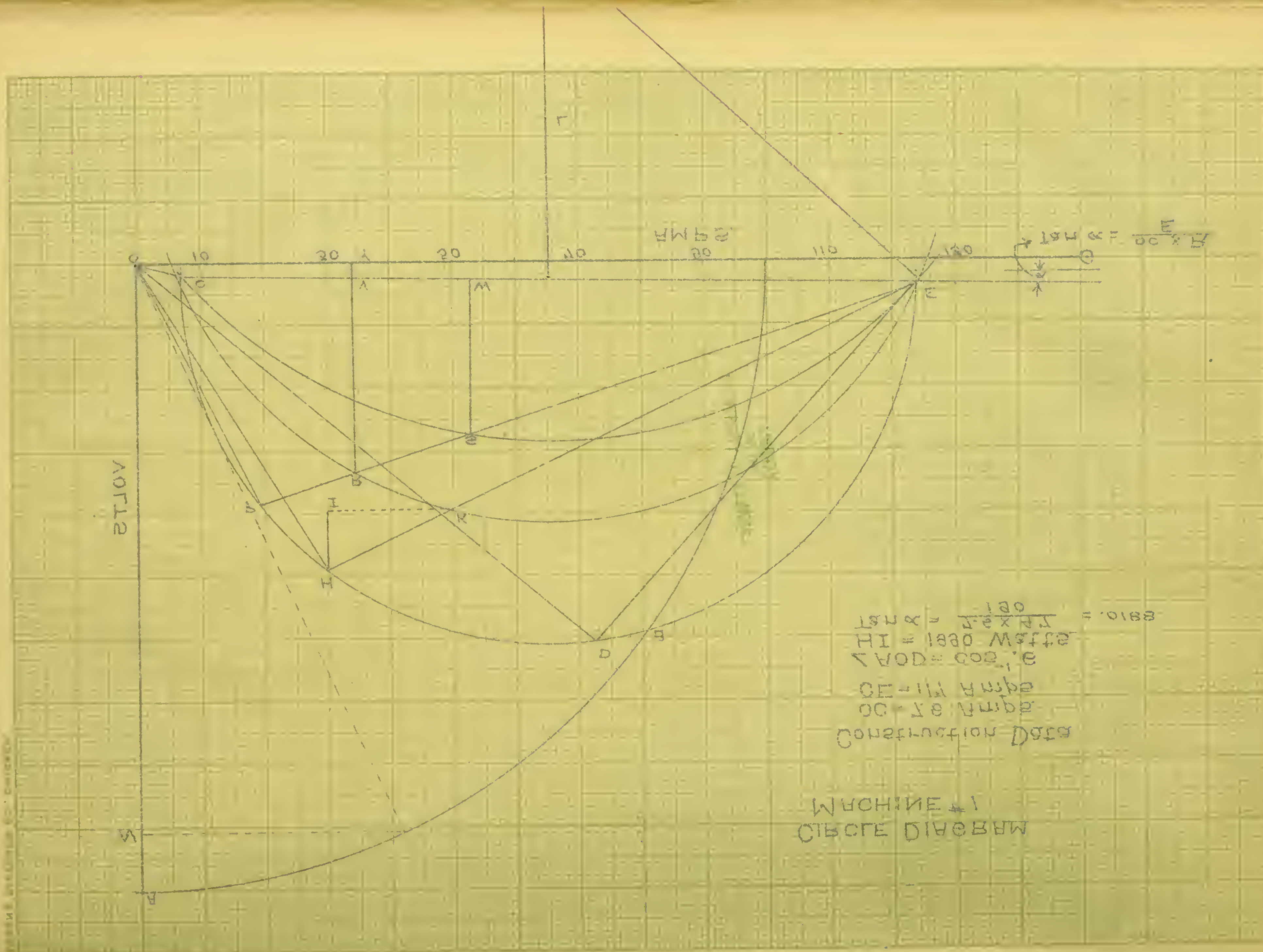
To draw any conclusions from the former data compared with the results of tests #1 to 6 it must be remembered that these results marked "Data from Circle Diagram Machines in Concatenation" are for a ratio approximately 1200 to 0 or an infinite ratio of speeds.

In justification of the above means of comparing the machines we refer the reader to "The Induction Motor" by B. A. Behrend p. 84.

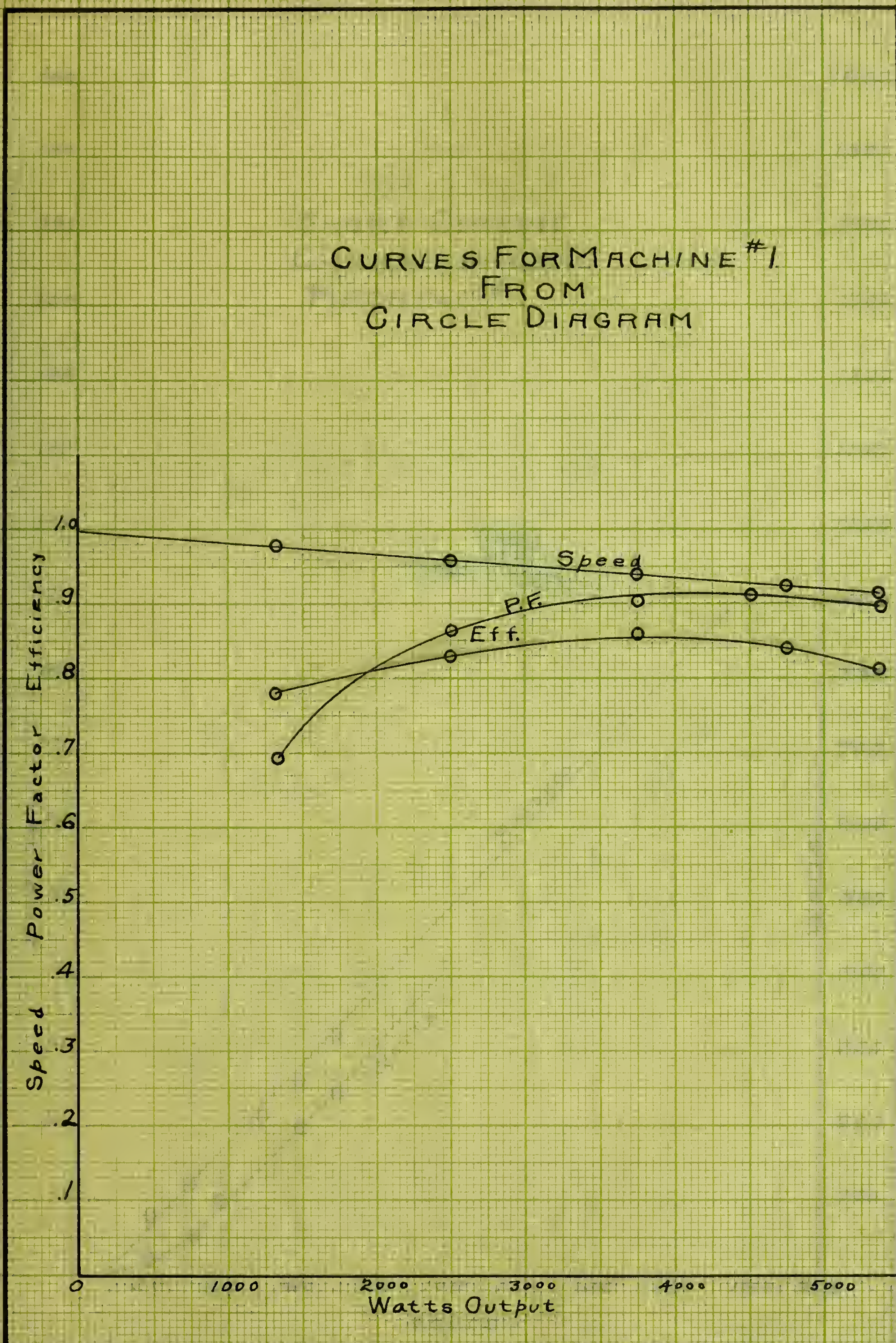
In conclusion a comparison of the results obtained from the three circle diagrams show that the efficiency and power factor are reduced by concatenation. The torque, however remains the same; see C. P. Steinmetz third edition p. 260.

Note:-- The circle diagrams shown are reduced by a scale factor from the originals which were many times larger to insure greater accuracy.


CIRCLE DIAGRAM
MACHINE #1.
Construction Data
OC = 7.6 Amps.
CE = 117 Amps.
∠AOD = cos⁻¹ .6
HI = 1990 Watts.
Tan α = 7.6 x 47 / 190 = .0188
Tan α = OC x R / E
VOLTS
AMPS.
0
10
30
50
70
90
110
130
A
N
D
B
H
K
P
I
R
S
C
V
Y
W
E
G
L
α

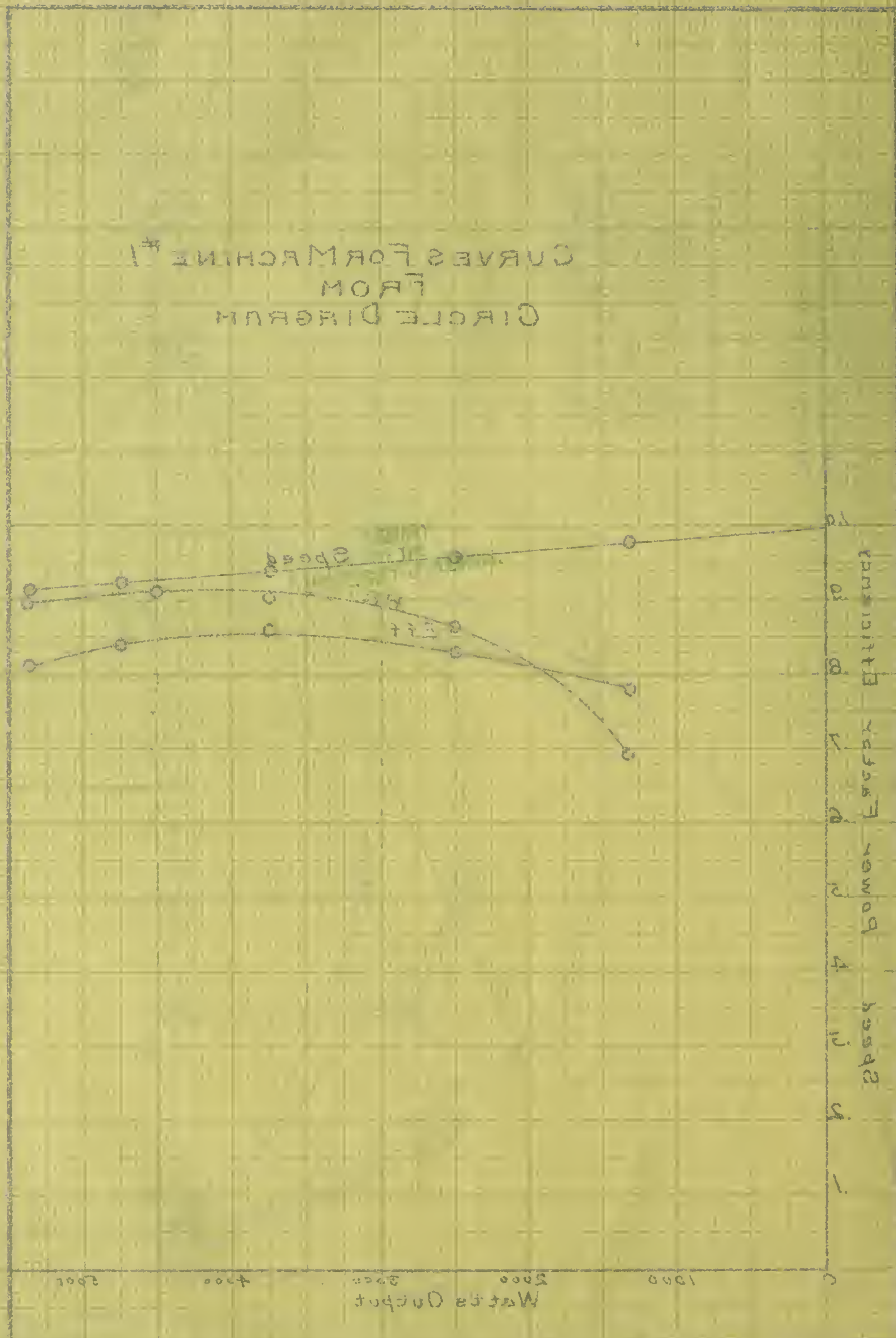


CIRCLE DIAGRAM
MACHINE #1
Construction Data
OC = 7.6 Amps
OE = 117 Amps
∠AOD = cos⁻¹ .9
HI = 1990 Watts
tan α = 190 / (7.6 x 117) = .0188
tan α = E / (OC x R)
AMPS
VOLTS
10
30
50
70
90
110
130

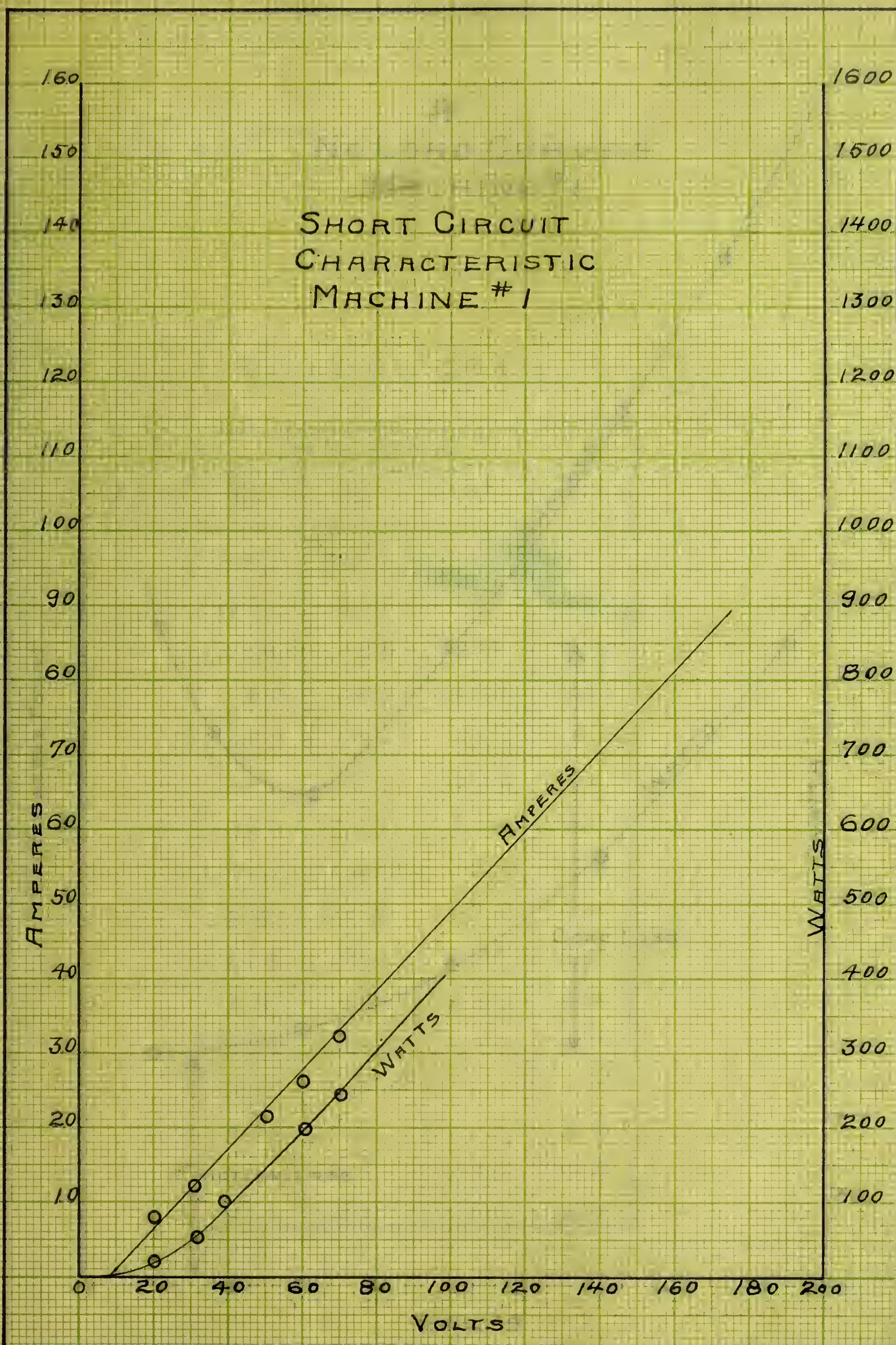


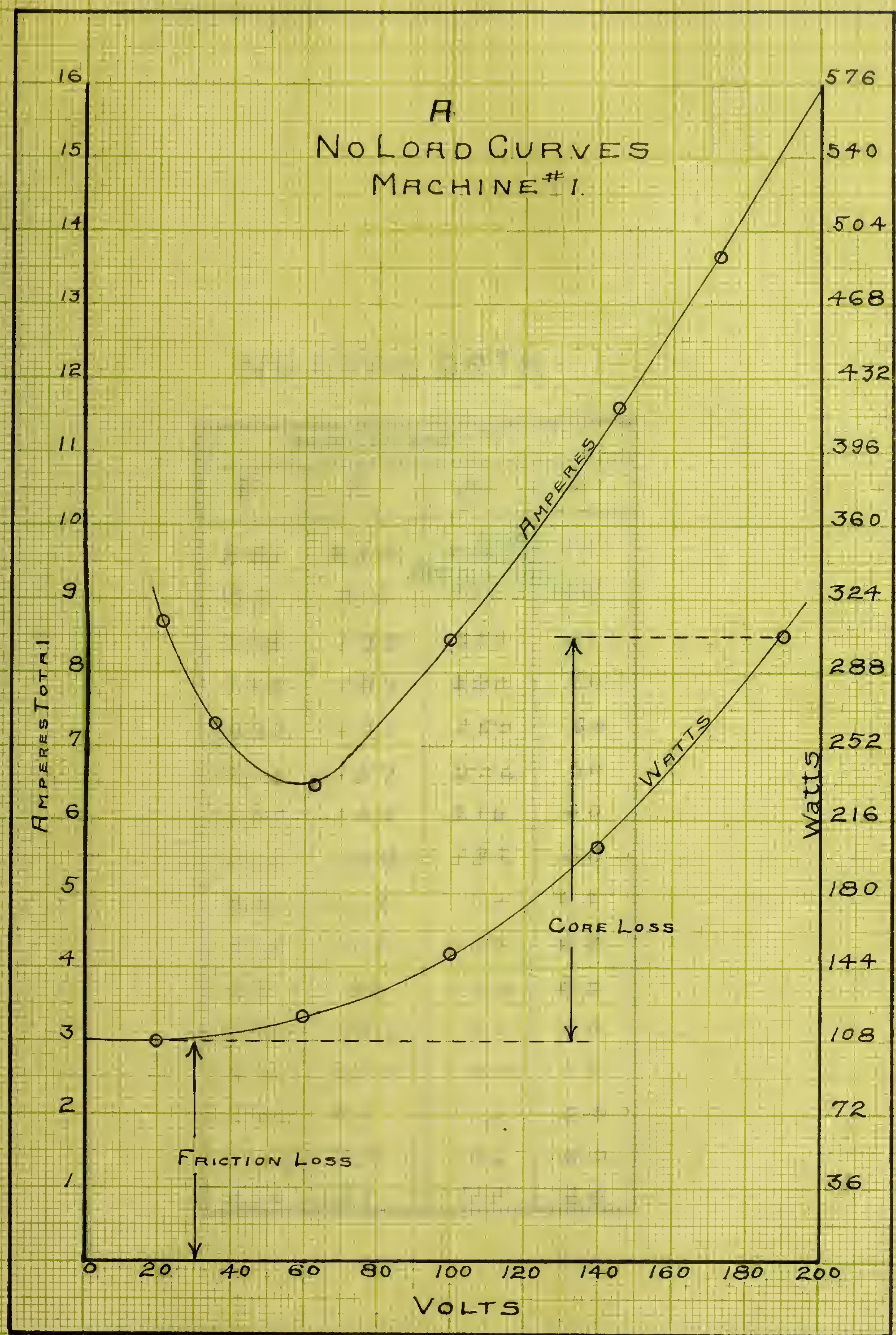
CURVES FOR MACHINE #1
FROM
CIRCLE DIAGRAM
Speed
P.F.
Eff.
Speed Power Factor Efficiency
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
1000
2000
3000
4000
5000
Watts Output

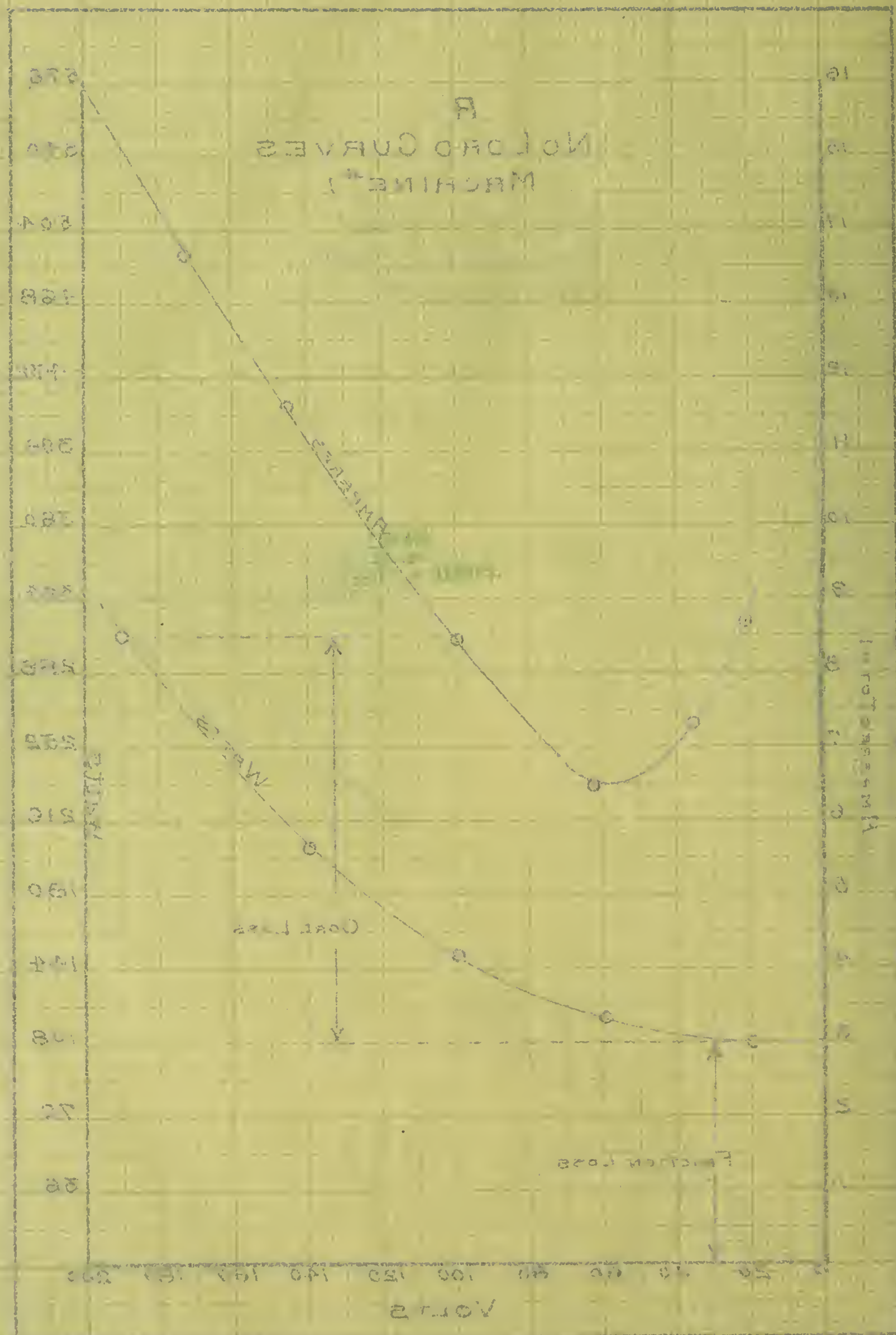
C.D. I.


CURVES FOR MACHINE #1
FROM
CIRCLE DIAGRAM
Speed
P.F.
Eff
Speed Power Factor Efficiency
Watts Output
0
1000
2000
3000
4000
5000
1
2
3
4
5
6
7
8
9
10

C.D.1


Short Circuit
Characteristic
Machine #1
Amperes
Watts
Amperes
Watts
Volts
0
20
40
60
80
100
120
140
160
180
200
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600


A
No Load Curves
Machine #1.
Amperes
Watts
Core Loss
Friction Loss
Amperes Total
Watts
Volts
0
20
40
60
80
100
120
140
160
180
200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
36
72
108
144
180
216
252
288
324
360
396
432
468
504
540
576


A
No Load Curves
Machine #1
Amperes
Watts
Core Loss
Friction Loss
Volts

NO LOAD DATA

MACHINE #1			
I	E	W	f
8.81	224	400	60
8.2	210	370	60
7.78	199	330	60
7.25	187	290	60
6.62	171	250	60
6.14	157	226	60
5.67	145	216	60
5.15	128	192	60
4.6	114	176	60
4.13	100	150	60
3.9	90	150	60
3.44	78.5	130	60
3.32	62.5	120	60
3.46	45	110	60
3.56	35	106	60
4.14	21	70	60

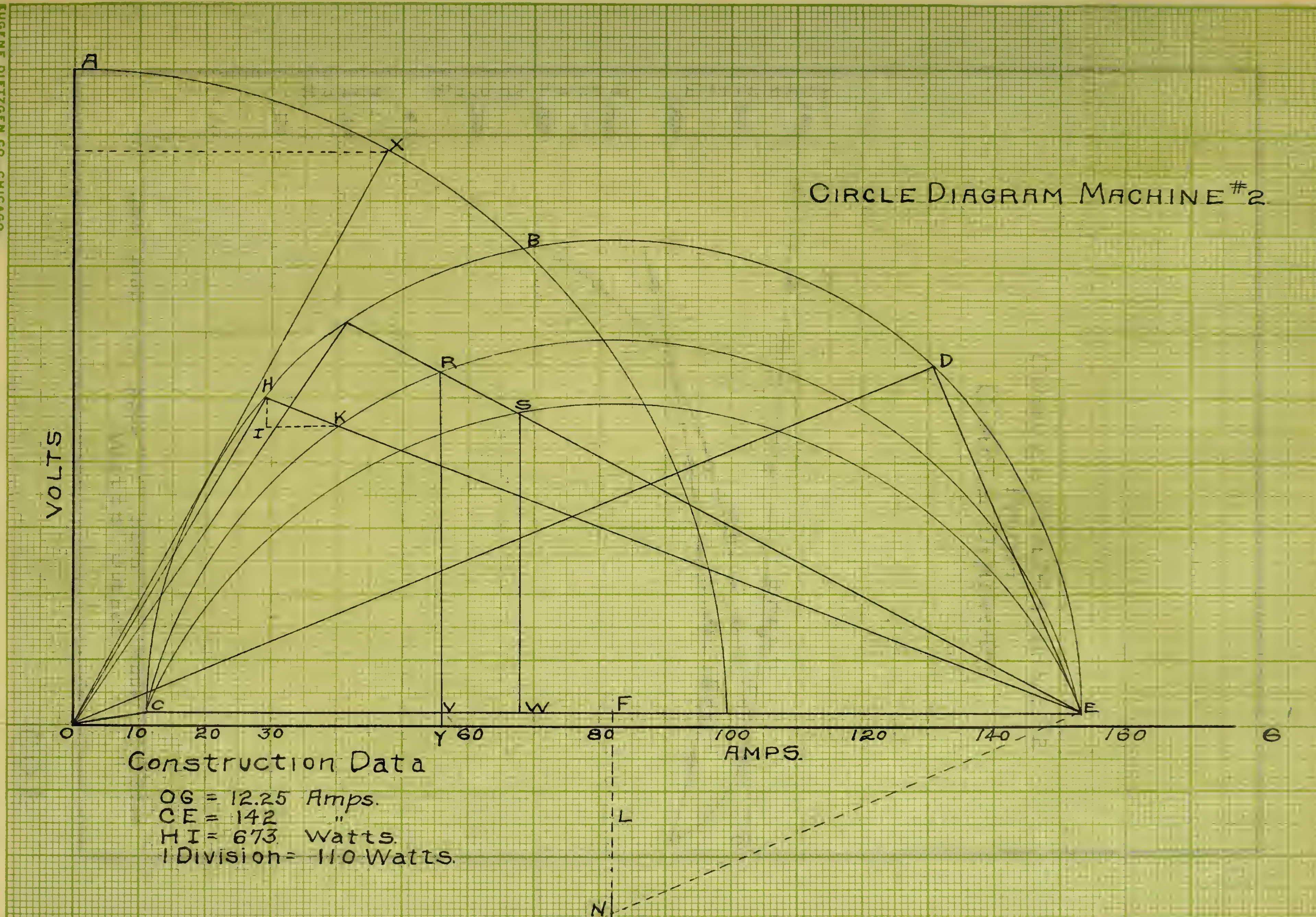
Machine # 1

SHORT CIRCUIT DATA					
E	I_A	W_A	W_B	I_B	f
9.	1.32	8	4	1.1	60
14.1	2.62	8	4	2.4	"
20.	8.18	80.	80	7.75	"
23.	8.74	84.	88	8.3	"
24.2	10.	120.	120	9.53	"
31	13.	180	220	12.2	"
39.4	15.7	241	400	16.3	"
49.5	19.5	480	540	21.9	"
60.	23.8	680	800	26.4	"
70	28.5	99.2.	992	29.2	"

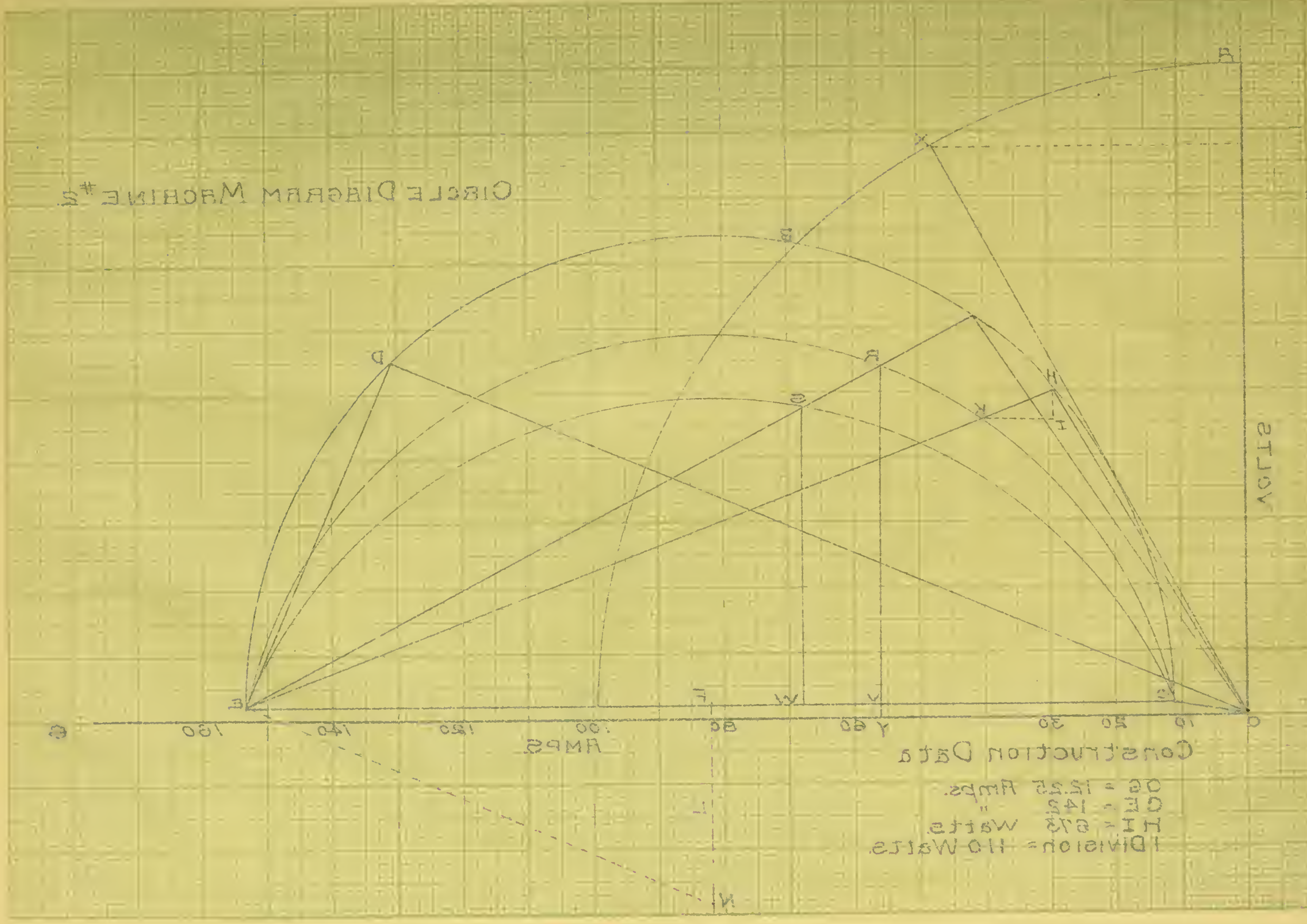
MACHINE #1.

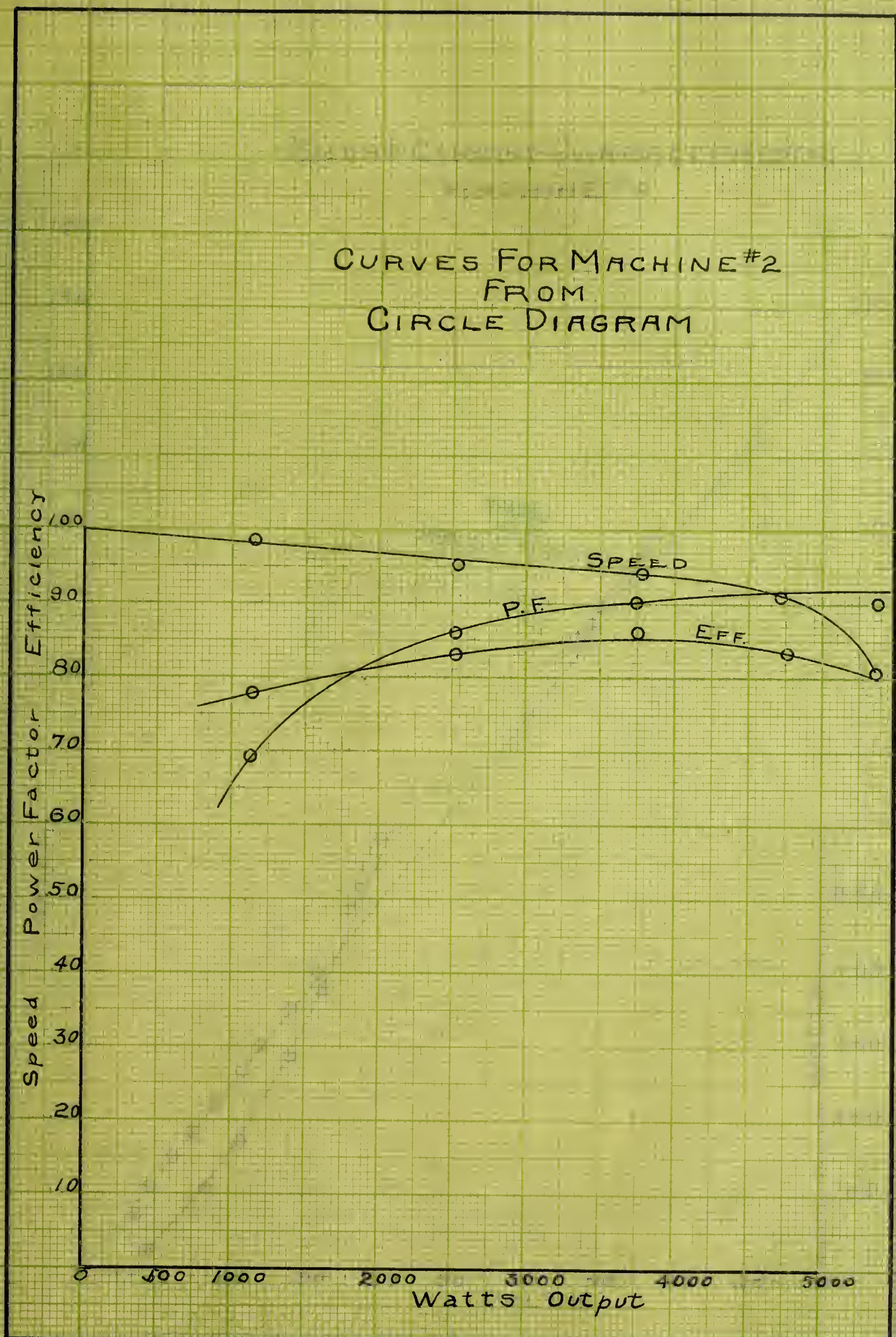
DATA TAKEN FROM CIRCLE DIAGRAM							
INPUT			OUTPUT	EFF.	P.F.	SLIP	SPEED
AMPS.	WATTS	VOLTS	WATTS	%	%	%	R.P.M.
10	1700	190	1330	78	69	1.8	1178
16	3000	190	2510	83	86	4.4	1146
24.6	4370	190	3770	86	90	5.8	1130
32	5700	190	4750	84	91	7.3	1112
40	6580	190	5360	81	90	8.5	1097

MAXIMUM P.F. .91



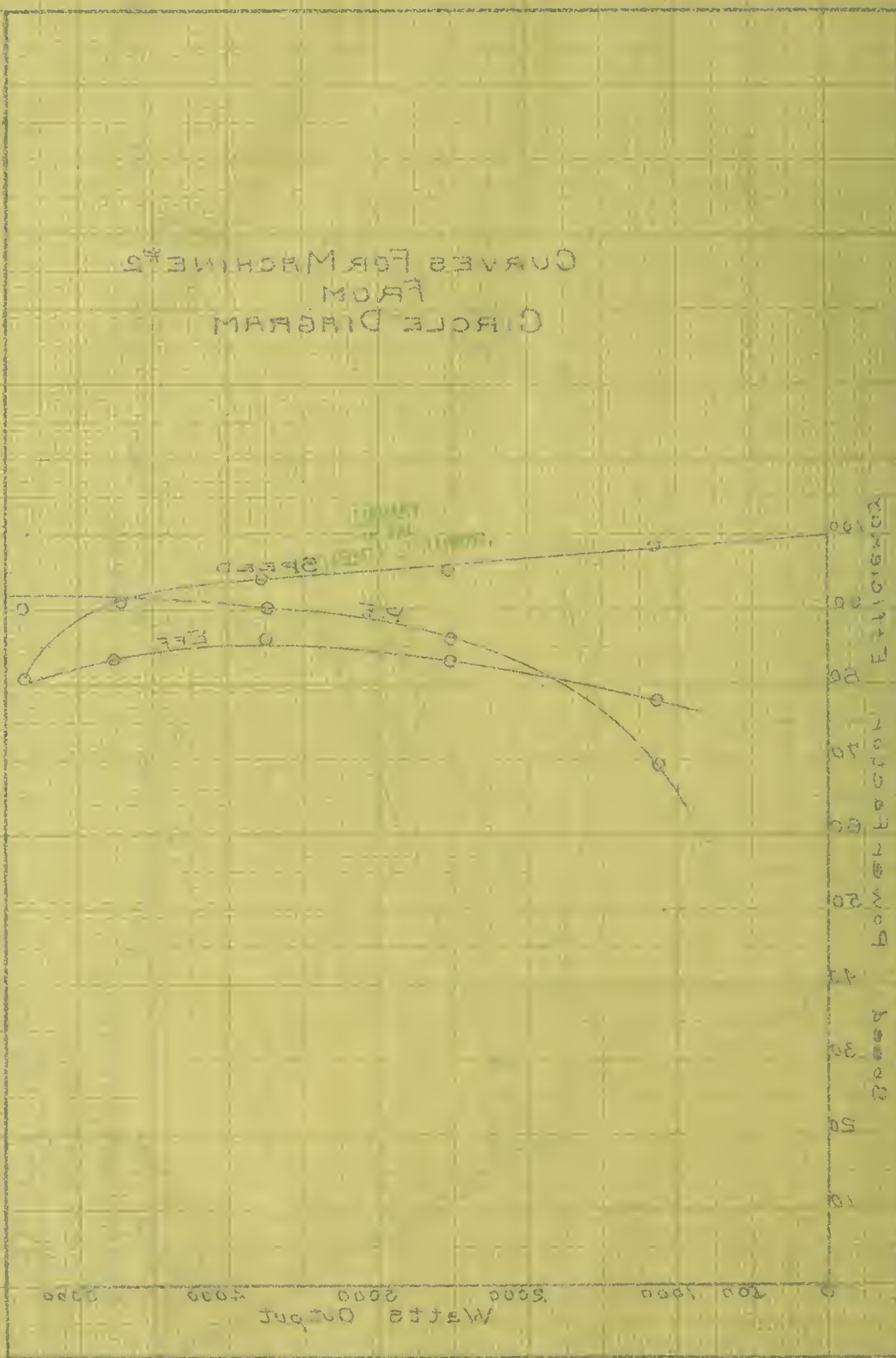
EUGENE DIETZGEN CO., CHICAGO.


Circle Diagram Machine #2
Construction Data
OG = 12.25 Amps.
OE = 142 "
HI = 673 Watts
1 Division = 110 Watts
AMPS
VOLTS



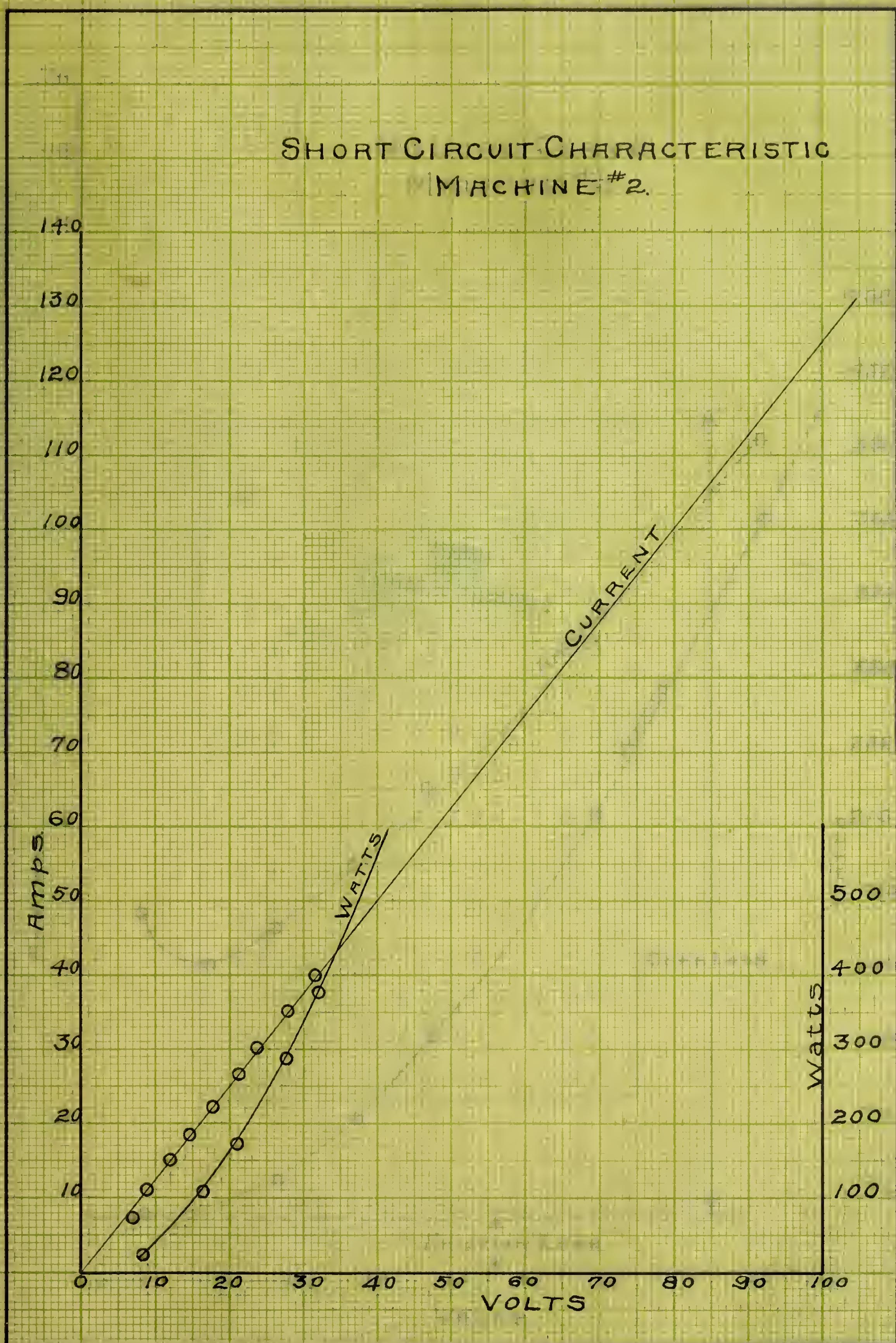
CURVES FOR MACHINE #2
FROM
CIRCLE DIAGRAM
SPEED
P. F.
EFF.
Speed Power Factor Efficiency
100
90
80
70
60
50
40
30
20
10
0
500
1000
2000
3000
4000
5000
Watts Output

C.D. 2.

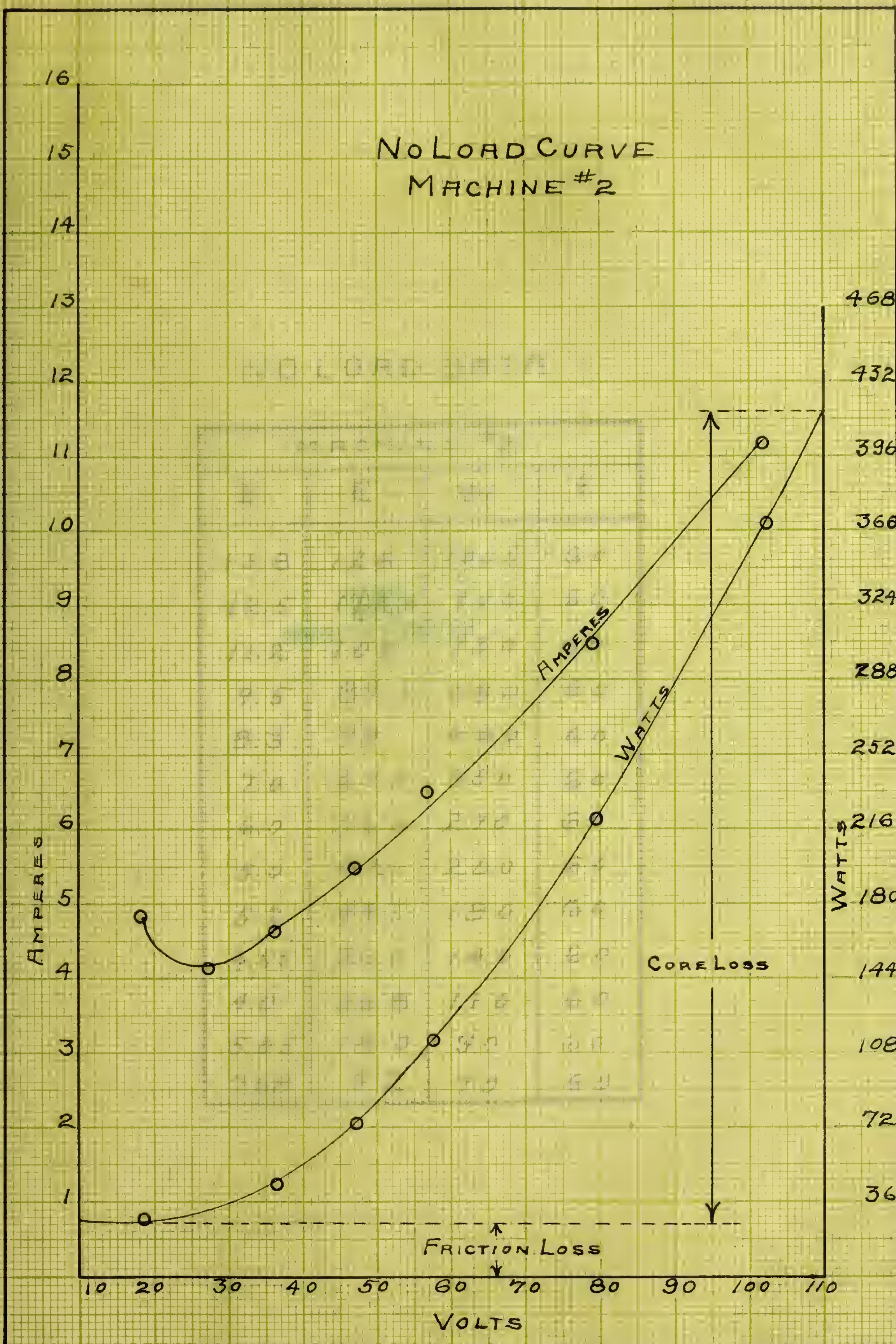


CURVES FOR MACHINE #2
FROM
CIRCLE DIAGRAM
SPEED
P.F.
EFF
Watts Output
Speed Power Factor Efficiency

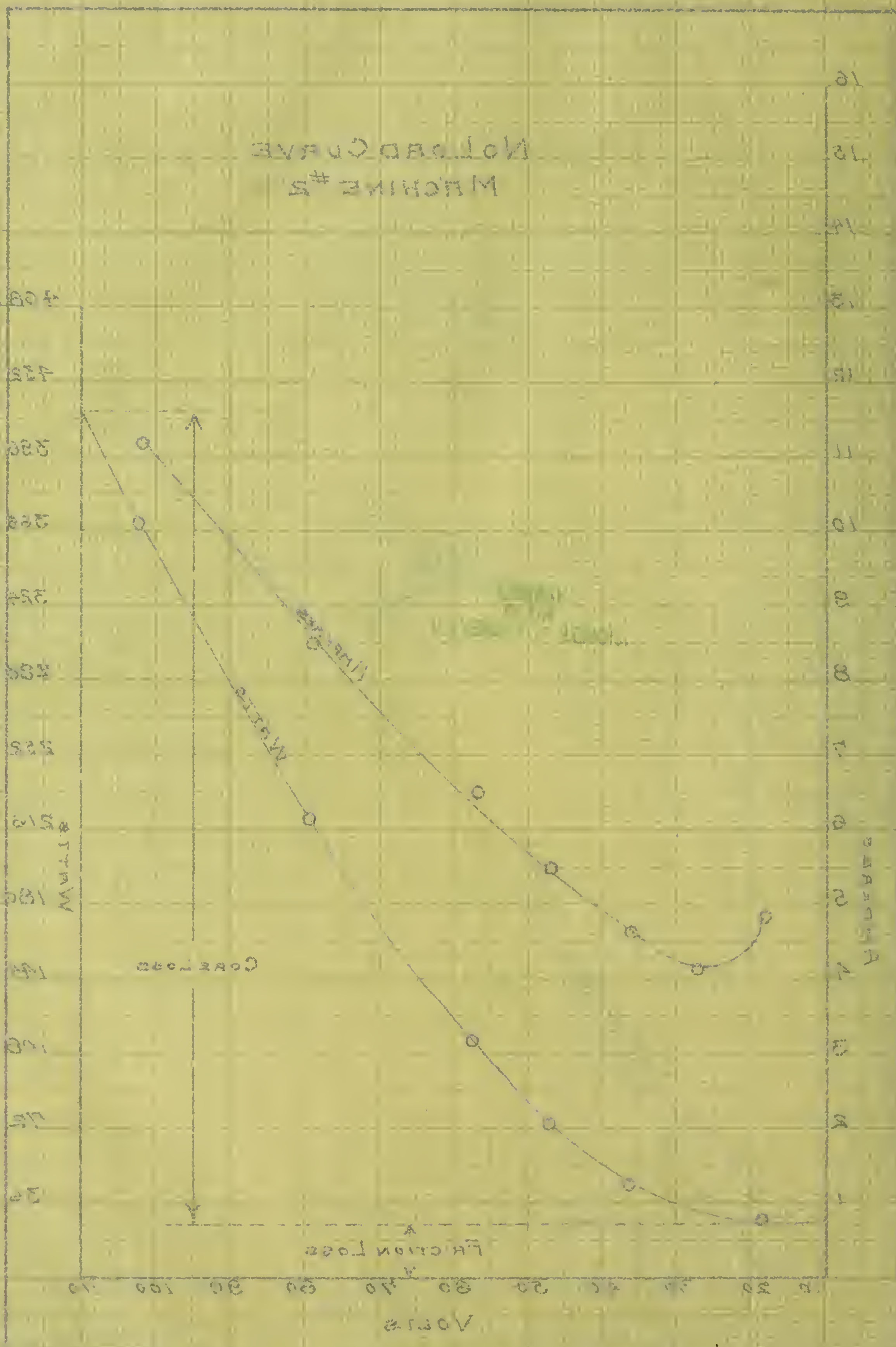
C.D. 2.



SHORT CIRCUIT CHARACTERISTIC
MACHINE #2.
Amps
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
VOLTS
Watts
500
400
300
200
100
CURRENT
WATTS



No Load Curve
Machine #2
Amperes
Watts
Core Loss
Friction Loss
Volts
10 20 30 40 50 60 70 80 90 100 110
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
36 72 108 144 180 216 252 288 324 366 396 432 468


No Load Curve
Machine #2
Watts
Amperes
Core Loss
Friction Loss
Volts

NO LOAD DATA

MACHINE #2			
I	E	W	f
13.8	126	1005	60
12.5	112.5	880	60
11.2	102	730	60
9.5	89.3	580	60
8.3	79	460	60
7.0	67.5	350	60
6.0	56.6	270	60
5.0	47.0	200	60
5.2	44.5	180	60
4.55	36.0	140	60
4.0	26.8	110	60
5.05	18.0	90	60
7.68	9.2	70	60

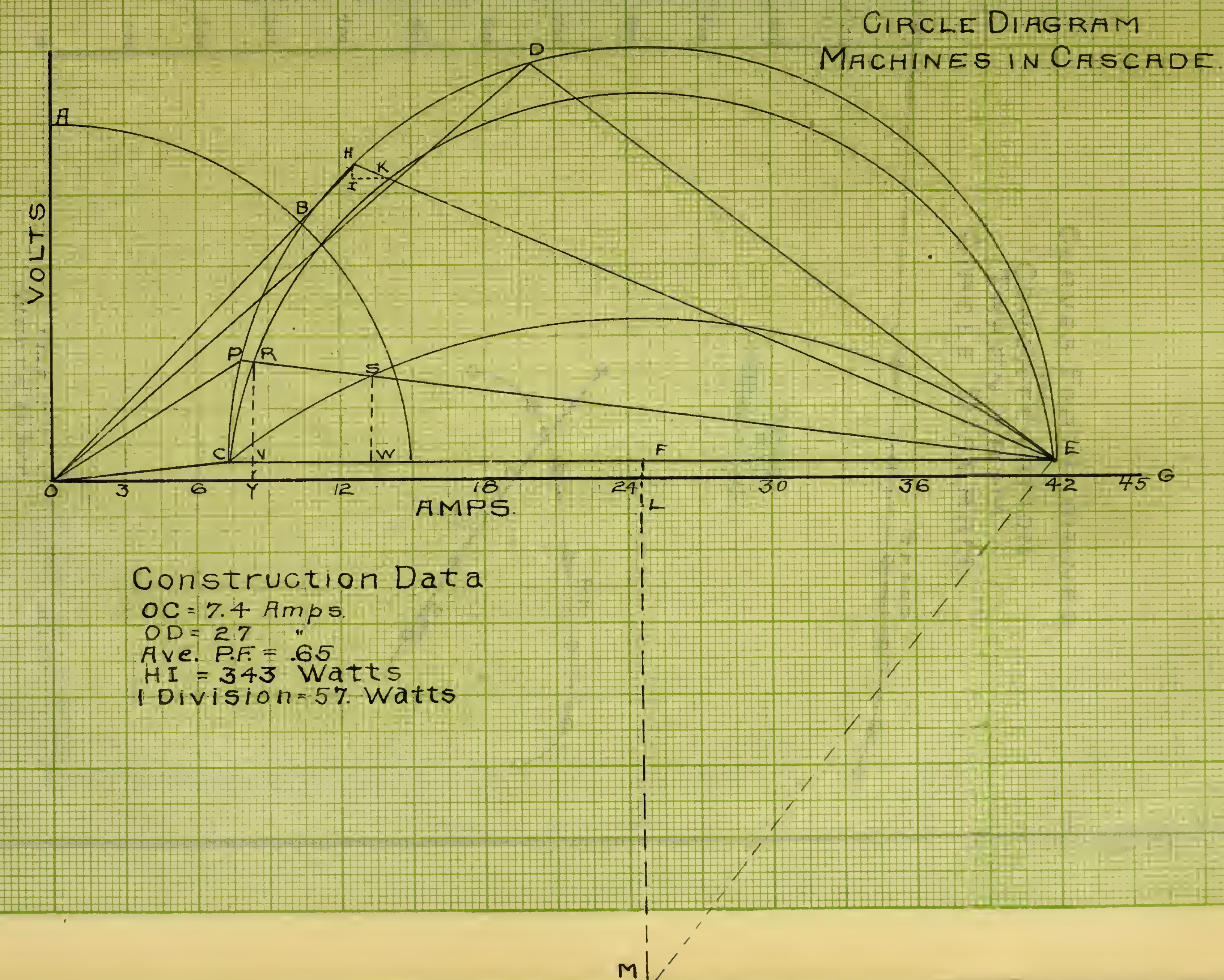
Machine #2

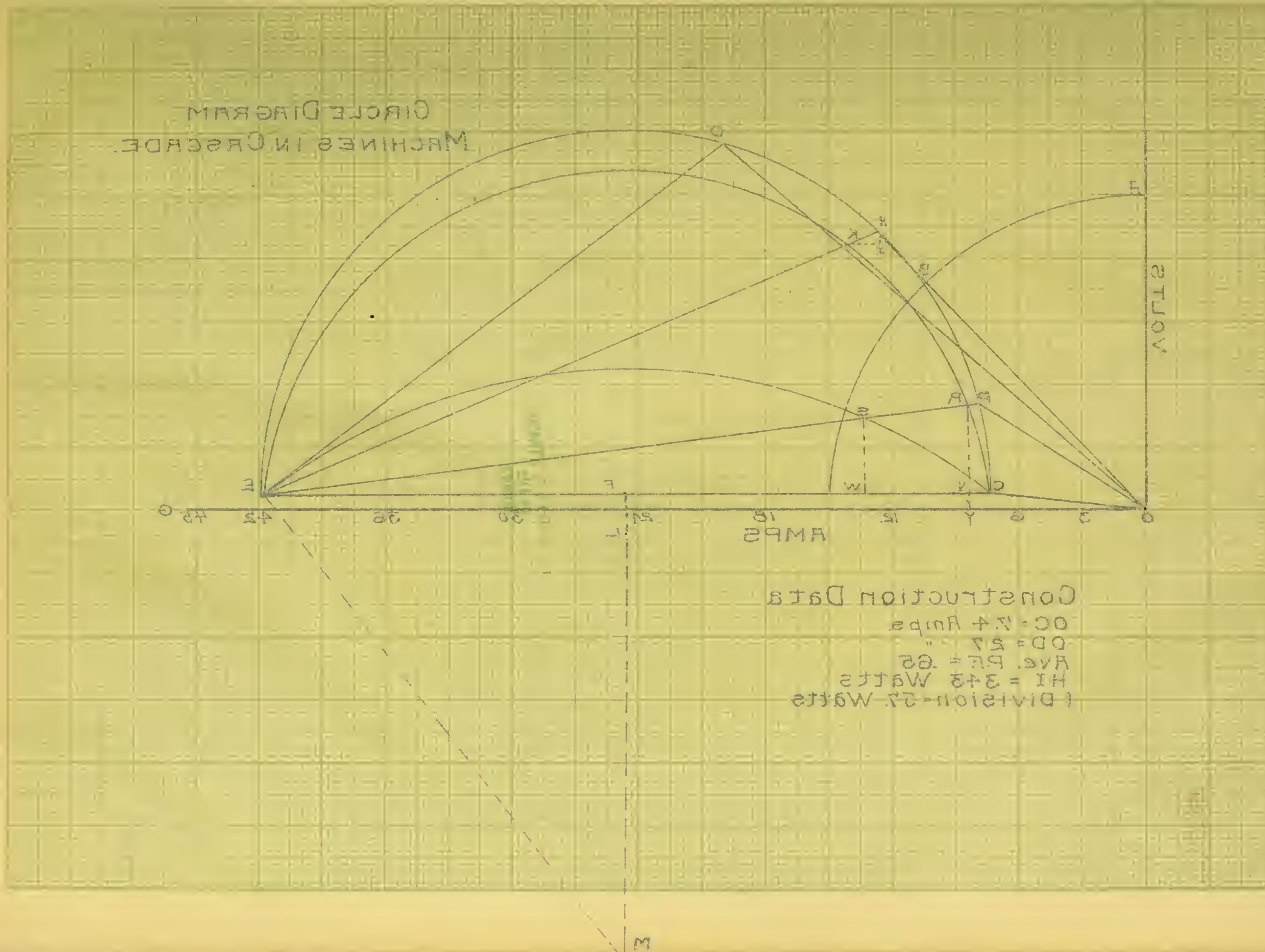
SHORT CIRCUIT DATA					
E	I_A	W_A	I_B	W_B	f
7.4	9.5	60	—	9.6.8	60
8.4	108	70	—	11.0	"
11.7	15.4	157.	10	15.2	"
14.1	18.2	240	10	18.5	"
17.5	22.2	333.	20	22.3	"
21.	27.	490	29	26.8	"
235	30.4	620	34	30.3	"
27.5	35.8	840	35	35.5	"
31.5	40.5	1110	40	41.	"

MACHINE #2

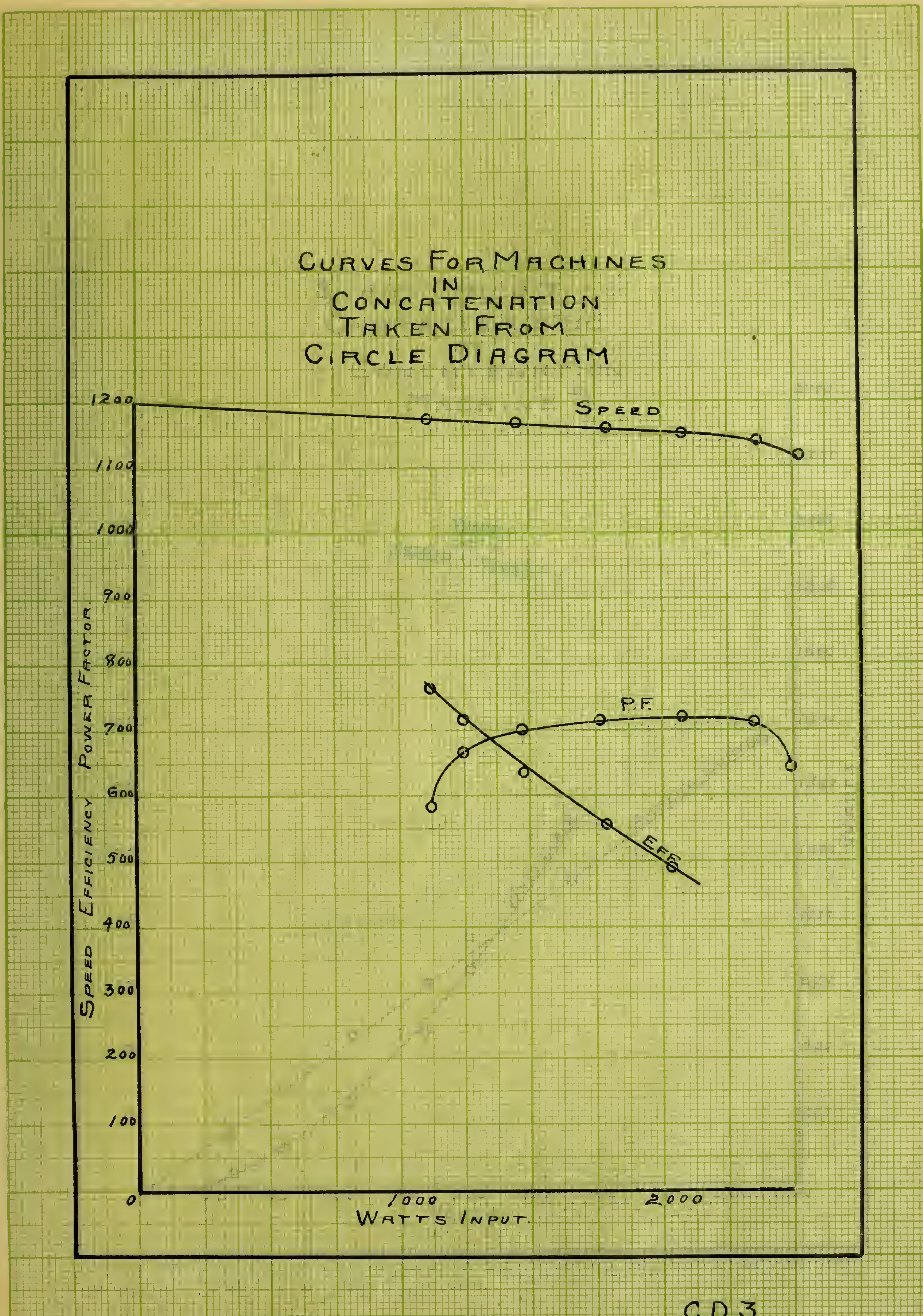
DATA TAKEN FROM CIRCLE DIAGRAM							
INPUT			OUTPUT	EFF.	P.F.	SLIP	SPEED
AMPS.	WATTS	VOLTS	WATTS	%	%	%	R.P.M.
16	1166	110	669	.57	69	2.9	1166
24	2112	110	1670	.80	83	2.6	1169
32	2915	110	2420	.83	87	2.64	1168
36	3263	110	2750	.84	88	3.1	1163
40	3630	110	3125	.86	88.5	4.1	1151

MAXIMUM P.F. .885

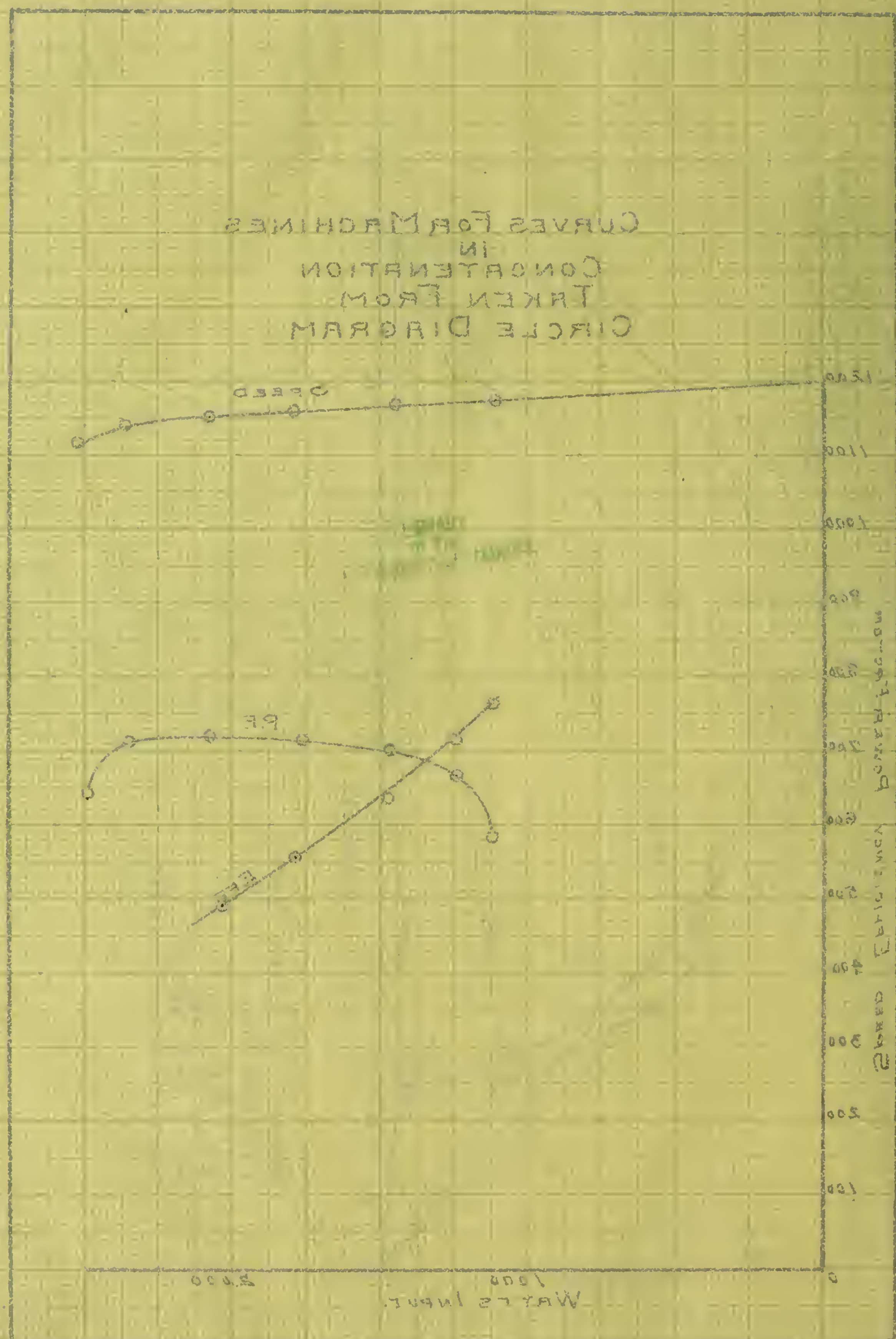

CIRCLE DIAGRAM
MACHINES IN CASCADE.
VOLTS
AMPS.
A
B
C
D
E
F
G
H
I
K
L
M
P
R
S
V
W
Y
0
3
6
12
18
24
30
36
42
45
Construction Data
OC = 7.4 Amps.
OD = 27 "
Ave. P.F. = .65
HI = 343 Watts
1 Division = 57 Watts



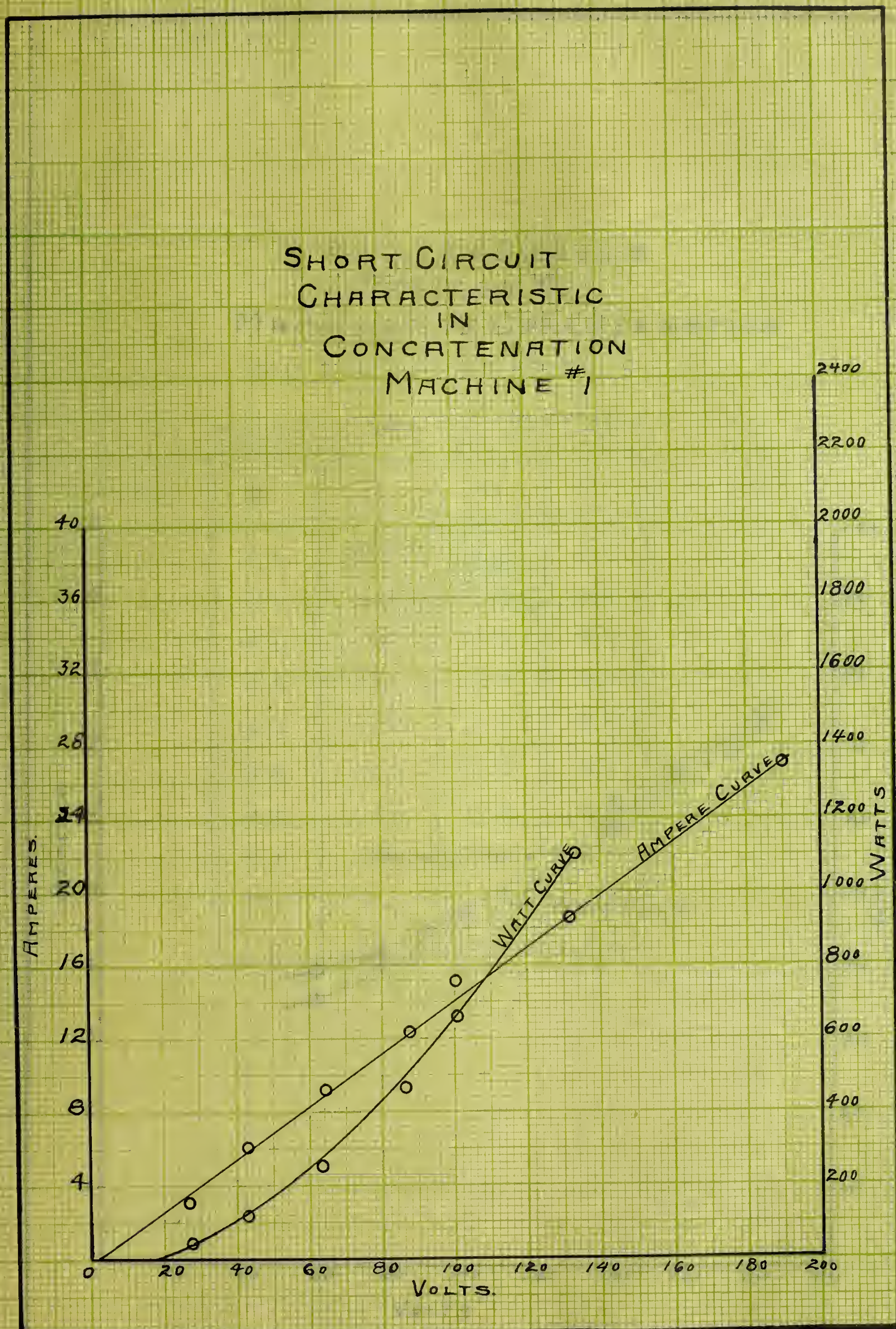
Circle Diagram
Machines in Cascade.
VOLTS
AMPS
Construction Data
OC = 7.4 Amps.
OD = 27 "
Ave. P.F. = .65
HI = 343 Watts
1 Division = 57 Watts



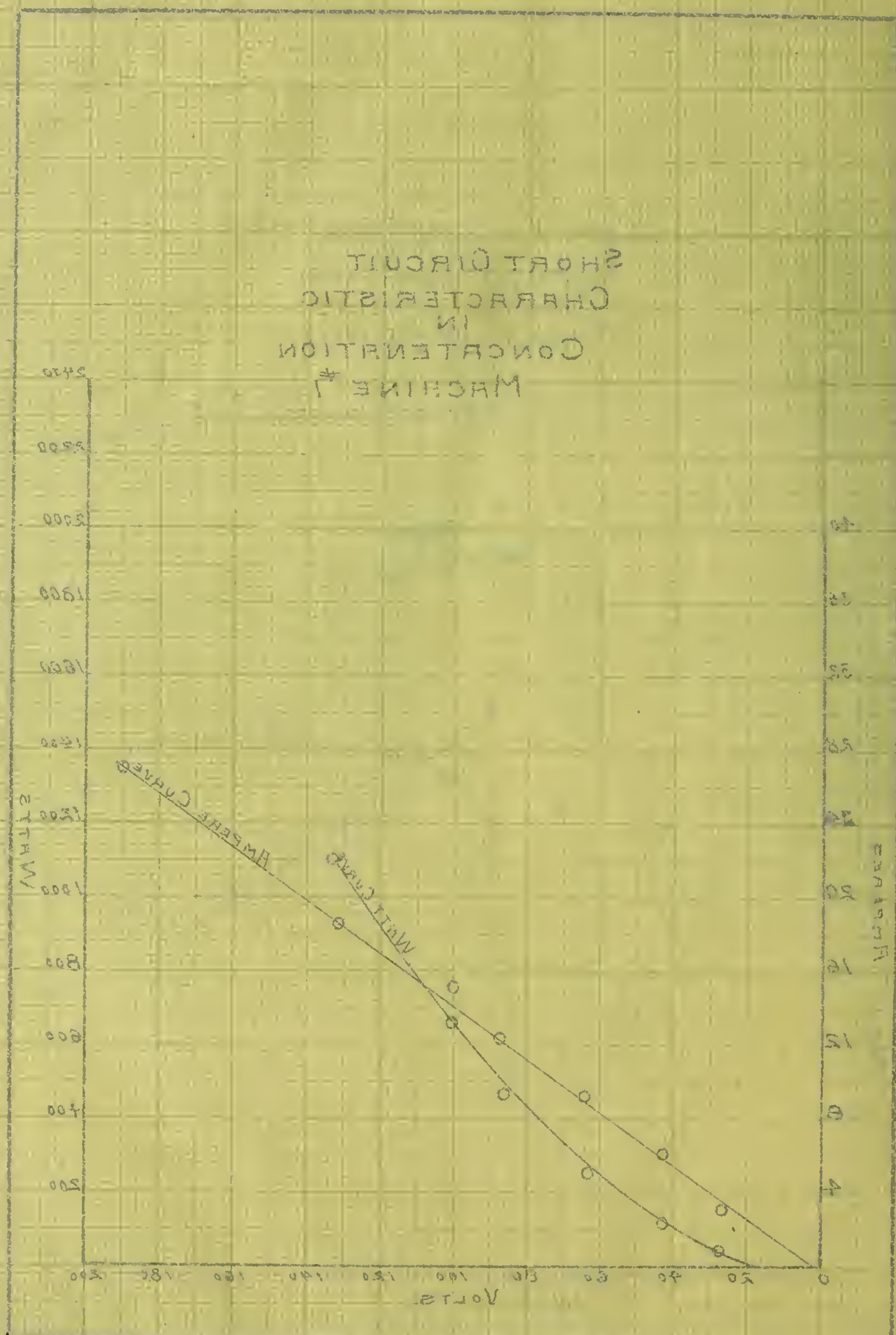
EUGENE DIETZGEN CO., CHICAGO.

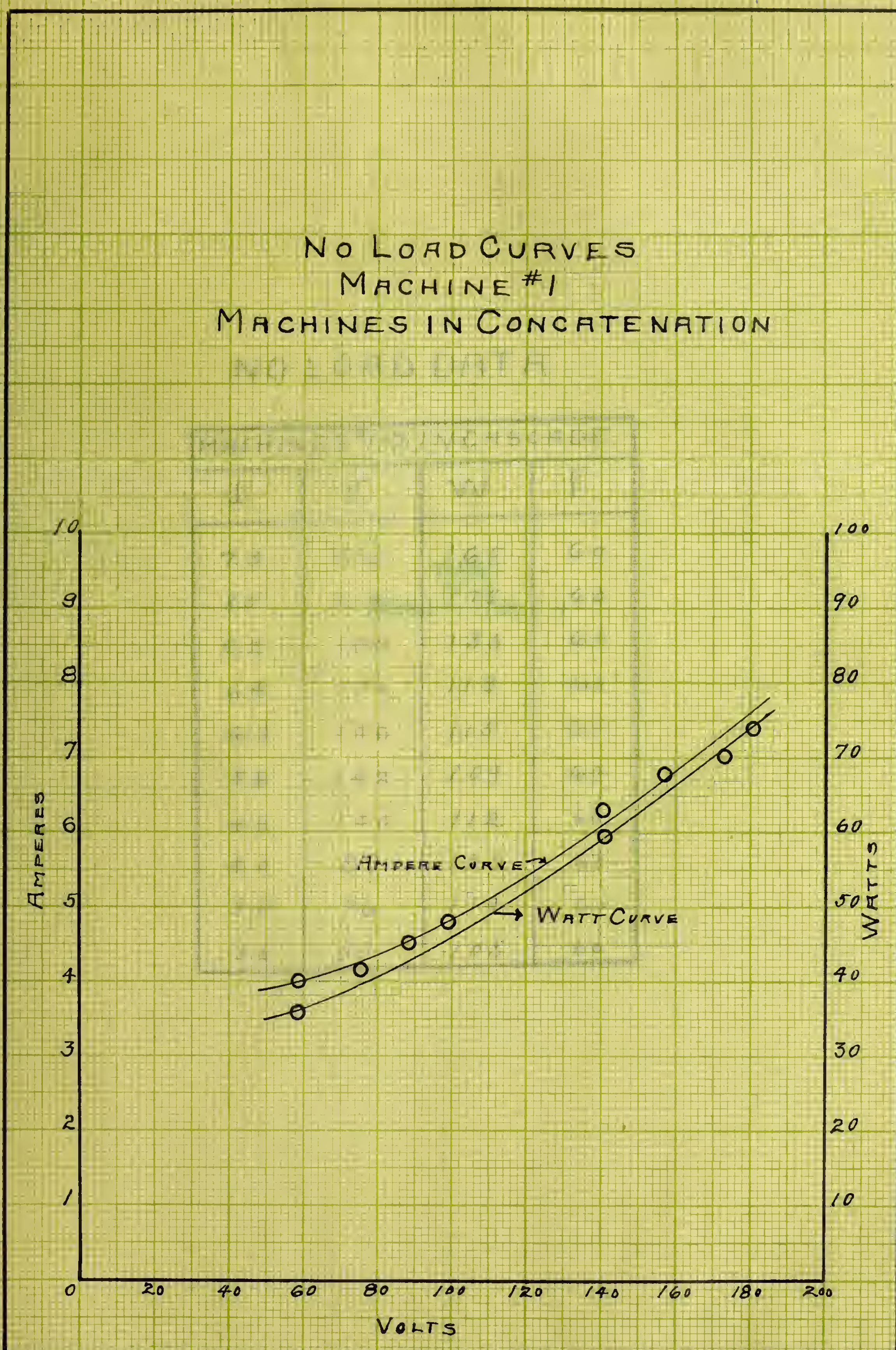


CURVES FOR MACHINES
IN
CONCATENATION
TAKEN FROM
CIRCLE DIAGRAM
SPEED
P.F.
EFF.
Speed Efficiency Power Factor
Watts Input



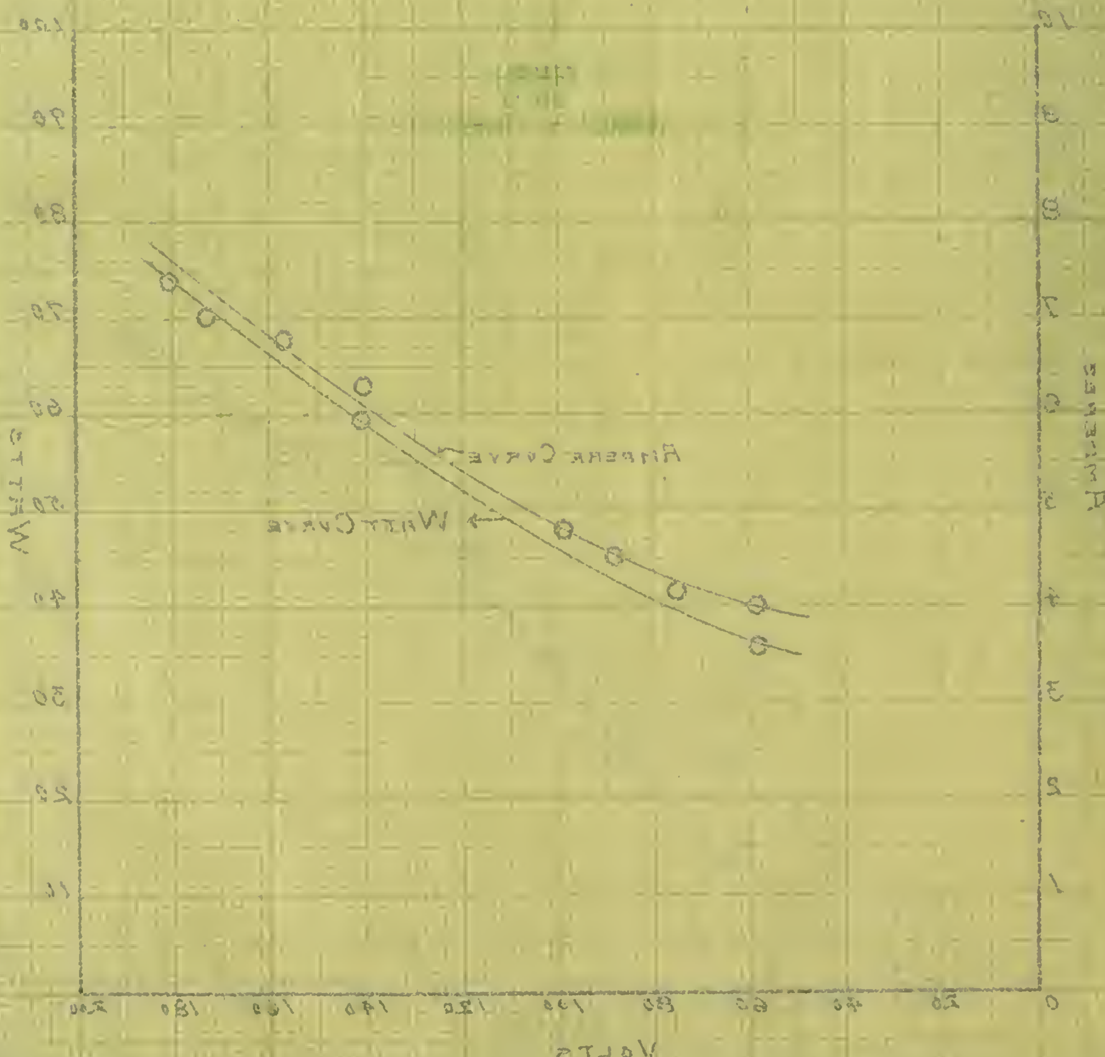
SHORT CIRCUIT CHARACTERISTIC IN CONCATENATION MACHINE #1
AMPERES.
40
36
32
28
24
20
16
12
8
4
0
20
40
60
80
100
120
140
160
180
200
VOLTS.
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
WATTS
WATT CURVE
AMPERE CURVE


Short Circuit
Characteristic
in
Concatenation
Machine #1
Ampere Curve
Watt Curve
Watts
Amperes
Volts



NO LOAD CURVES
MACHINE #1
MACHINES IN CONCATENATION
AMPERES
WATTS
VOLTS
AMPERE CURVE
WATT CURVE
0
1
2
3
4
5
6
7
8
9
10
10
20
30
40
50
60
70
80
90
100
20
40
60
80
100
120
140
160
180
200

No Load Curves
Machine #1
Machines in Concatenation



NO LOAD DATA

MACHINES #1+2 IN CASCADE.			
I	E	W	f
7.3	202	165	60
8.0	218	175	60
6.2	180	133	60
6.8	174	119	60
6.3	156	115	60
5.8	142	109	60
4.2	100	112	60
4.0	89	122	60
3.8	76	119	60
3.6	59	105	60

SHORT CIRCUIT DATA.#					
E	I_A	W_A	I_B	W_B	f
25	3.66	40	3.66	40	6.0.
42.5	6.03	115	6.03	115	"
63.5	9.2	260	9.2	260	"
87.	12.2	445	12.2	460	"
100	15.2	610.	15.2	650	"
132	18.5	1000	20.0	1100	"

#Machines in Concatenation.

MACHINES #1 + #2.
IN CONCATINATION.

DATA TAKEN FROM CIRCLE DIAGRAM							
INPUT			OUTPUT	EFF.	P.F.	SLIP	SPEED
AMPS.	WATTS	VOLTS	WATTS	%	%	%	R.P.M.
10	1090	190	830	.76	.58	1.77	1179
12	1460	190	1038	71	67	2.53	1170
14	1790	190	1140	64	70	3.35	1160
16	2070	190	1158	56	72	4.12	1150
18	2305	190	1114	48	72	4.78	1143
20	2520	190	982	39	72	5.92	1129

MAXIMUM P.F. .72

Conclusions.

The low power factors and efficiencies noted in these tests appear on the surface very discouraging as to the practical application of tandem control of induction motors. Efforts to raise the power factor by the use of capacity in the secondary circuit were far from successful. All other means for the accomplishment of this much desired feature were unavailing. The small output of the tandem machines compared with that of the single motor shows no promising future for cascade connections.

Considerations other than the above, however, compel the writers to agree with S. P. Thompson, as quoted on page 2.

The primary of machine one was wound such as to be well adapted to tandem connection, but its secondary could probably have been improved for our tests by reducing the resistance per circuit and increasing the turns per coil. The primary of the second machine was wound for 38 amperes at 110 volts, and had a comparatively high resistance. Much better results could be obtained by having the primary of machine number two wound for the voltage at the terminals of the secondary of the first machine, at the desired speed, and having the resistance of the primary of the second motor less than the necessary resistance which, if added to the secondary of motor number one, when operated singly, would bring the maximum torque of that motor at the speed required.

That is, if the primary of motor number one were wound for 200 volts, its secondary delivering 100 volts at stand still, and double the current of the primary, then, for a ratio of speeds

1 - 2, the secondary delivers 50 volts to the primary of the second motor. The latter should be wound for this voltage, and its resistance should be determined as above.

For machines which are to be operated on the same circuit in parallel for high speed, they should be wound for the same voltage, Far more important is it, however, that the ratio of primary turns to secondary turns shall equal unity in the combined operation of motors in tandem and parallel, than obtains in tandem operation alone.

A connection that may be recommended for motors to be operated in parallel on the primary circuit, and, also, in cascade is that:

1.-- The first machine shall have ratio of primary turns to secondary turns equal to unity.

2.-- The primary of the second machine shall have its primary such that the coils may be connected in series for parallel operation and in parallel for tandem connections.

Under these above conditions, we see no reason why efficiencies of 85% or greater could not be obtained together with higher power factors in tandem connection.

With machines properly designed this method of operation to secure reduced speed can be recommended.

It has been our endeavor throughout this work to draw such conclusions and to make such predictions from the results as can be proven. Our entire sources are laid open to the reader and we invite inspection believing that the unprjudiced will not only accept our statements and predictions but will, in view of greater experience, go farther in claiming success for tandem operation of induction motors.

List of References.

"Alternating Current Motors" by A. S. McAllister

"Polyphase Electric Currents" by L. P. Thompson

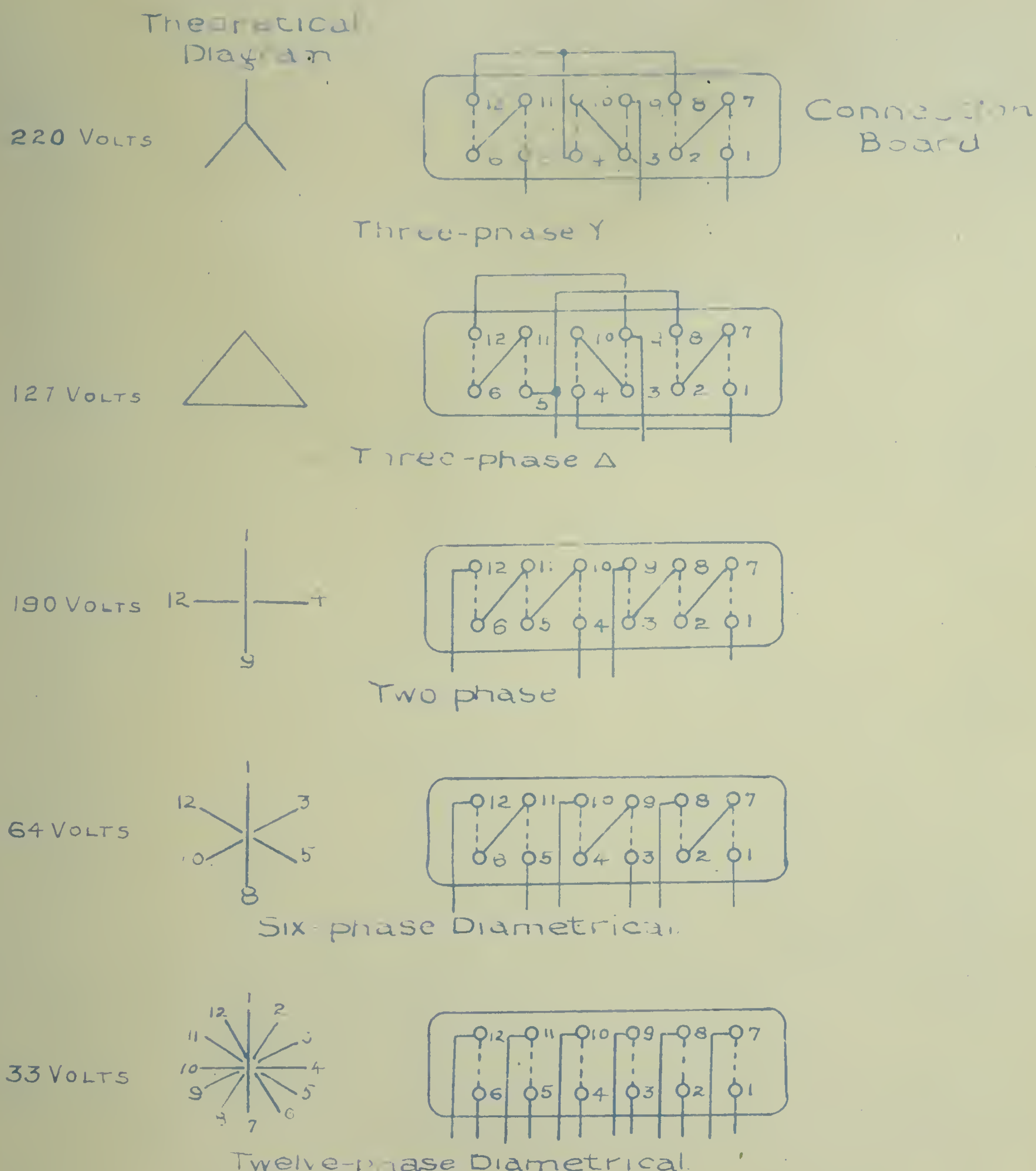
"Alternating Current Phenomena" by C. P. Stienmetz

"Elements of Electrical Engineering" by C. P. Steinmetz

"Induction Motor" by B. A. Behrend

"Electrical World and Engineer" Volume 46, No. 26, Dec. 23, 1905.

Connections of
Special Twelve Terminal Alternating Current Generator or Motor



Dotted lines represent winding coils

PLATE 2

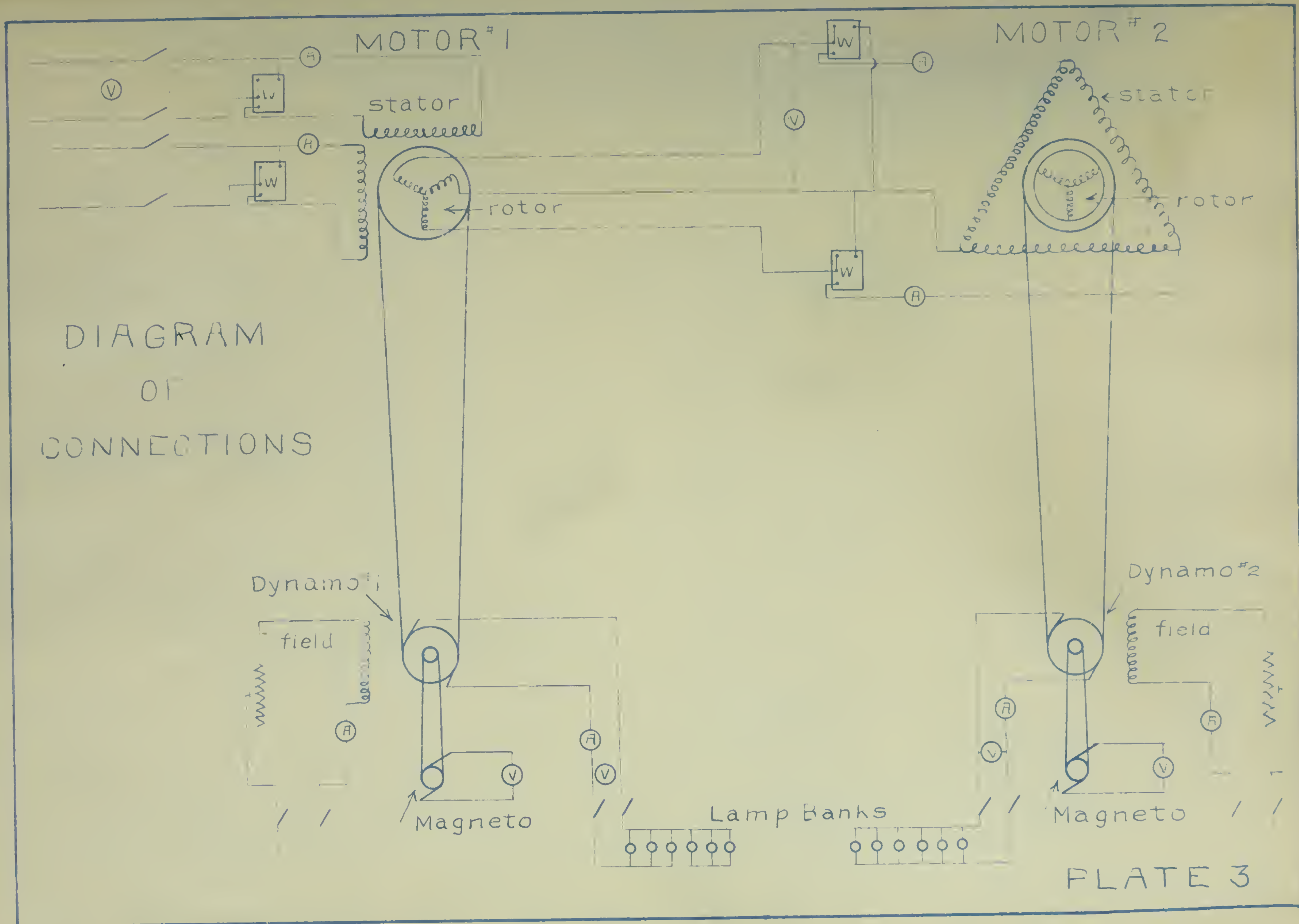

MOTOR #1
stator
rotor
MOTOR #2
stator
rotor
DIAGRAM
OF
CONNECTIONS
Dynamo #1
field
Magneto
Dynamo #2
field
Magneto
Lamp Banks
W
W
W
W
A
V

PLATE 3

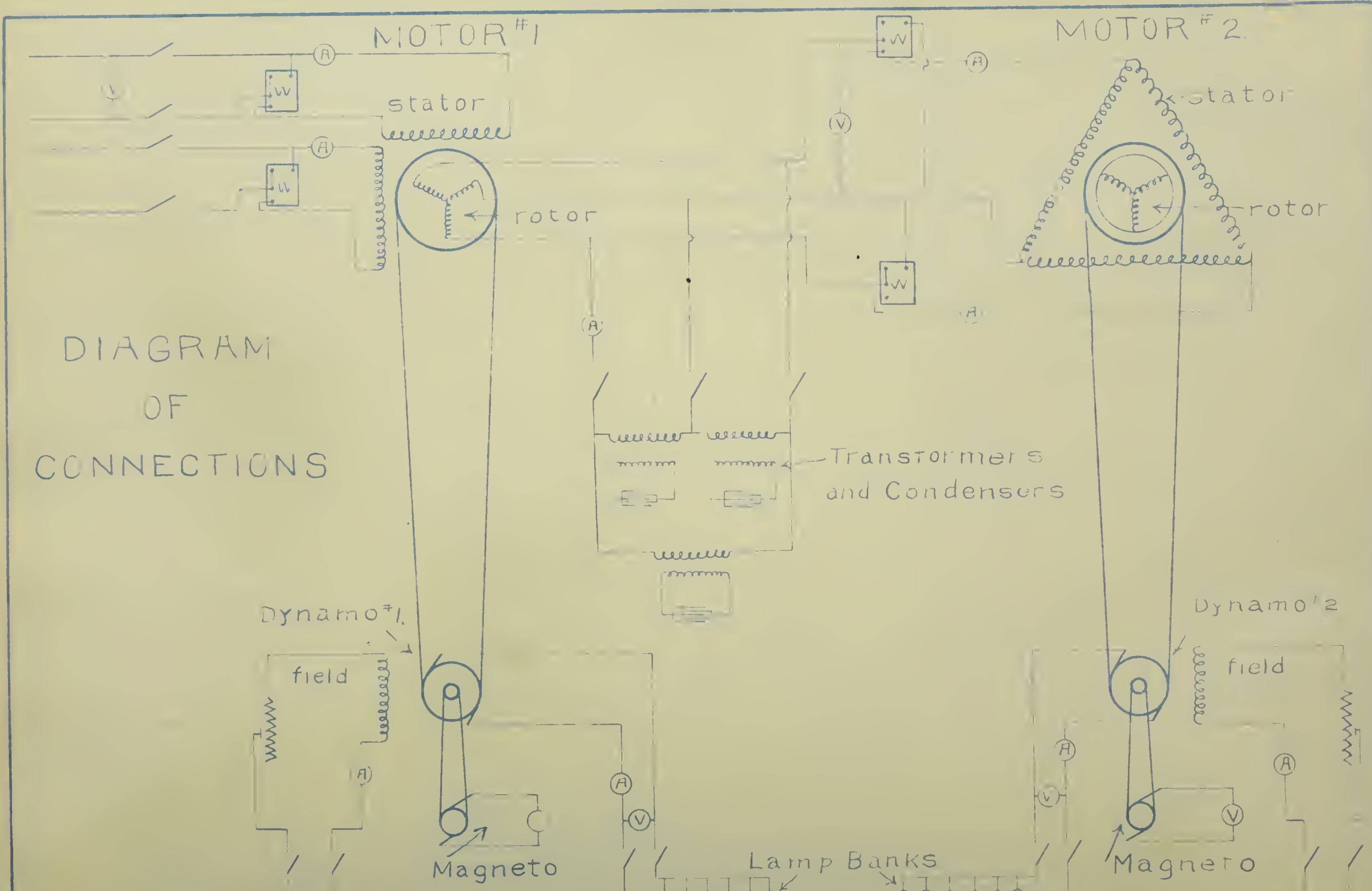

MOTOR #1
stator
rotor
MOTOR #2.
stator
rotor
DIAGRAM
OF
CONNECTIONS
Transformers
and Condensers
Dynamo #1.
field
Magneto
Lamp Banks
Dynamo 2
field
Magneto
A
V
W

PLATE 6.